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MIDWINTER CONVENTION NUMBER

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COMING MEETINGS

Midwinter Convention, New York, February 14-16

Spring Convention, Pittsburgh, April 24-26

Annual Convention, Swampscott, Mass., June, 25-29

Pacific Coast Convention, Del Monte, California, September 25-

MEETINGS OF OTHER SOCIETIES

American Electric Railway Association, Washington, D. C., February 15-16.

American Electrochemical Society, New York, May 3-5

American Institute of Mining & Metallurgical Engineers, New York, February 19-21

American Physical Society, New York, February 24; Washington, D. C., April 21

American Society of Mechanical Engineers, Montreal, March 28-31

Institute of Radio Engineers, New York, February 7

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Radiation from Transmission Lines*

BY CHARLES MANNEBACK

Electrical Engineer, Brussels, Belgium

Review of the Subject:— *The aim of this investigation was to contribute something to our knowledge of traveling electromagnetic waves. Among the transient phenomena that occur along transmission lines, these are still little known, especially as far as their "attenuation" and "distortion," or change in shape near the "wave front" are concerned.*

It is first seen that the "classical theory" of the propagation of electrical disturbances along lines, as it has been chiefly developed by Heaviside and Poincare, does not give a correct representation of the facts near the wave front, because it assumes an instantaneous penetration of the current in the wires. It is shown that this theory is an "unidimensional" one, as it considers only one space variable, the coordinate along the line, and, from an electromagnetic point of view, amounts to identifying the traveling waves with plane wave phenomena.

Steinmetz's theory of the radiation from traveling waves (TRANS. *A. I. E. E. Feb., 1919) is then examined, and, as Carson pointed out* (JOUR. *A. I. E. E., Oct. 1921), found based on a misconception of the propagation of the electromagnetic field near the wires of a line. It is remarked that this theory amounts to propagating longitudinal electric waves, a conception in conflict with the basis of Maxwell's theory. This latter proves very easily that, along a perfect line, i. e., without ohmic or leakage losses, plane electromagnetic traveling waves are propagated without distortion and without attenuation; hence that there is no radiation. Losses do not change anything from the radiation point of view (Mie. Ann. Phys. 2, 1900). In the theory of Steinmetz, the radiation was the controlling factor at high frequencies.*

Although the question could be considered as settled, in so far as Steinmetz raised it, it is felt that the conditions under which traveling waves are started must be elucidated, in order to decide whether, during the transient process of establishing a plane electromagnetic traveling wave, any loss of energy can occur by radiation in free space. This would reduce the radiation to a transient phenomenon instead of to a steady one, as assumed by Steinmetz, i. e., to an effect produced when the condition of plane wave is departed from, as at the origin or the end of a line ("end effect").

The problem, considered in its broad aspect, i. e., from the electromagnetic point of view of Maxwell, appears to be of great complexity. It involves a study of what might be called time-three-dimensional space transient, while the most complicated transients considered in electrical engineering are time-one-dimensional space transients, as was already noticed. It was found possible, however, to decide whether the radiation is a factor of enginering importance in attenuating and distorting waves.

There, first, the distribution of current along the conductors of a line is shown to be a very close approximation to the actual, unknown, distribution, with regard to the possibly existing radiation. Then, from this assumption, the radiation of the system is calculated at a corresponding approximation, and its amount found to be negligible compared to the heat dissipated in the line during the same time. From this it is concluded that the effect of the radiation upon the attenuation and the distortion of the waves along the line must also be negligible, compared to the effect of the joulian losses, and in this result a proof "a posteriori" of the correctness of the initial assumption is seen. The first idea of that procedure, but limited to stationary waves, is probably to be credited to M. Abraham (Phys. Zeit. 2-p. 329-1901) who applied it to the calculation of the radiation from a single isolated wire (oscillator), and found it in practical agreement with a more elaborate theory, based on Maxwell's equations. As in this latter application the radiation is larger than the ohmic dissipation, the conclusions of this investigation are even strengthened.

An application to the steady radiation from a transmission line oscillating freely at one of its natural frequencies shows, even at very high frequencies, that the power radiated is negligible compared to the heat dissipated. For instance, a 100-kilometer transmission line, No. 00 B. & S. wire, oscillating at three million cycles per second, wastes by radiation only 1/3600 of what is wasted by heat. This is in accordance with the results given for steady a-c. traveling waves along a line by Carson, (loc. cit.).

In the case of a traveling wave suddenly started at the origin of a perfect line, it is found that, when the wave has become plane, the amount of energy

$$\frac{3}{2}\, d\, 10^{-9}\, I^2 \text{ joules}$$

is wasted by radiation. d is the distance in cm. between the two wires of the line and I the constant current suddenly flowing in the line, in amperes. This energy is carried to infinity by an electromagnetic field limited to a thin spherical shell of variable depth, (not thicker than d), expanding at the speed of light. A reflection of the wave at a free end of a line is shown to add to the preceding an amount of radiated energy

$$4\, d\, 10^{-9}\, I^2 \text{ joules}$$

and only half that amount for a grounded line. A complete transposition causes a radiation four times as large as the sudden starting of the wave. Compared to the joulian dissipation during the time the wave takes to travel once along the line, the radiated energy is of the order of 1/10,000th.

The influence of the radiation on the attenuation and distortion of traveling waves is thus found entirely negligible in engineering practise. Other possible factors are suggested.

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*This paper is the result of an investigation submitted in partial fulfillment of the requirements for the degree of Doctor of Science from the Massachusetts Institute of Technology, 1922. It has been undertaken under the direction of Professor V. Bush, to whom the author wishes to express his fullest appreciation.

To be presented at the Midwinter Convention of the A. I. E. E., New York, N. Y., February 14-17, 1923.

INTRODUCTION

ONE of the chief reasons at present limiting the development and interconnection of high-power and long-distance electrical transmission lines is the trouble due to the occurrence of abnormal voltages and abnormal currents in the line and the connected apparatus. Whenever any change occurs in

the steady state conditions of an electrical system, *e. g.* by connecting or disconnecting a load, or by producing or interrupting a short circuit, the new steady state conditions are generally reached after a very short time, during which so-called "transient phenomena" or "transients" take place. As the flow of effective and reactive power are not the same in the different parts of the system during the first and the second steady state, the necessary adjustment is made by transient electromagnetic "traveling waves," *i. e.* waves of both voltage and current, carrying energy from one part of the system to another.

The values of voltage and current in these waves, or as we shall say the amplitude of the waves, may reach abnormally high values and become destructive to the line. The steepness of the front of the wave also, *i. e.*, the high rate of change of the voltage and current with the time may be harmful. Therefore, a knowledge of the "attenuation" or diminution of amplitude of the wave with the time, and of the "distortion" or change in the wave shape, is of engineering importance. Our present knowledge of the subject is still far from being complete. Joulian and dielectric losses produce both attenuation and distortion, but there may be other causes. C. P. Steinmetz[1] considered the possible influence of radiation, but his results may be questioned.

From this began the present investigation, aiming towards the determination of the radiation effect upon the decay of traveling waves along transmission lines. It was found that the radiation effect is entirely negligible compared with the effect of joulian dissipation, and hence that, from an engineering point of view radiation can be ignored in connection with transmission lines.

Classical Theory of the Propagation of Waves Along Electric Lines

The classical theory of the propagation of waves along a line, *i. e.*, a system of straight parallel outgoing and return conductors, rests upon two assumptions: the displacement currents in the dielectric, parallel to the conductors are negligible, and the so-called "four distributed constants" of the line can be determined. They are the resistance, inductance, leakance and capacity per unit length of the line (R, L, G, C). These quantities are functions of the frequency for sinusoidal steady alternating current; for transient currents, they are somewhat indeterminate, and an average value must be assumed.

The fundamental equation for the propagation of the voltage V or the current I is under these assumptions

$$L\,C\,\frac{\partial^2 V}{\partial t^2} + (R\,C + L\,G)\,\frac{\partial V}{\partial t} + R\,G\,V = \frac{\partial^2 V}{\partial x^2} \tag{1}$$

where t denotes the time and x the space coordinate along the line. From this equation, well known conclusions can be drawn, of which the following only need be considered here:

1. An electric disturbance, *i. e.*, a discontinuity of voltage or current, is always propagated along any line at the constant speed $v = 1 : \sqrt{L\,C}$, whether there is resistance and leakance or not.
2. The disturbance is attenuated exponentially with the time according to

$$\exp\left[-1/2\,(R/L + G/C)\,t\right].$$

3. The distortion of the disturbance depends on the value of the term

$$1/2\,(R/L - G/C)\,.$$

In the case of transmission lines, the attenuation is the controlling factor, and the wave has died out before any appreciable distortion has taken place. Thus a steep wave front will very nearly keep its shape during the propagation.

This conclusion, however, is based on the two assumptions made; the first amounts to saying that the variations of V and I along the line will not be too rapid, and the second, that the penetration of the current in the wires is instantaneous, neither of which is true at the very front of the wave. From Maxwell's point of view, the classical theory amounts to a plane wave theory, *i. e.*, the electromagnetic field around the wires lies in planes; this implies that the dissipation is taking place everywhere in the plane wave, instead of being localized in the wires. This has been shown very clearly by O. Heaviside in his "Electrical Papers."

We thus consider the question of change in the wave shape near the front of the wave, due to the resistance of the line, still as an open question.

Dr. Steinmetz's Theory of the Radiation

Dr. Steinmetz's theory of the radiation from transmission lines deals only with the electromagnetic field. The electric and the magnetic fields are supposed to propagate from the wires perpendicularly into space, thus implying a flow of energy from the wires into space, and also non-transversal electromagnetic waves, two conceptions in conflict with Maxwell's theory. It is shown[2], as an immediate deduction of Maxwell's equations that plane electromagnetic transversal waves are propagated undistorted and unattenuated, at the speed of light in the surrounding medium, along a pair of infinitely long straight perfect conductors, *i. e.*, along a line without joulian or leakage losses; thus there is no radiation. Nonperfect conductors, as it has been shown, introduce more complexity, because the waves are no more plane waves, but nothing is changed from the radiation point of view.[3] The flow of energy in the dielectric is evidently parallel to the wires, with a small component directed

1. C. P. Steinmetz—Proc. A. I. E. E., Feb. 1919, p. 249. —Transient Electric Phenomena, 1920; Sec. III, Chap. 8, 9; Sec. V.

2. H. Hertz, Wiedemann's Annalen, 36, p. 1, 1889. Die Ausbreitung der elektrischen Kraft, 1892. J. R. Carson, Jour. A. I. E. E., Oct. 1921, p. 789.

3. G. Mie, Annalen der Physik, 2, p. 201, 1900.

into the wires if there are losses. This settles entirely the question, in so far as Dr. Steinmetz raised it: *traveling plane* waves along a line are *not* attenuated nor distorted by radiation, *i. e.*, by escape of energy in a direction perpendicular to the line. Plane waves were an *implicit* assumption in the criticized theory; however, very near the source of a disturbance, or near the end of the line where reflection occurs, or in general near any place where there is a change in the geometrical or electrical behavior of the line, the electromagnetic field, of course, cannot be plane.

This raises a new question: If plane traveling waves are only a limiting state, is there not any radiation taking place when the electromagnetic wave is initiated? Or, otherwise expressed, is radiation not an "end effect" with respect to the line? This involves the consideration of the whole surrounding space as the seat of the phenomena, and we need to start from a broader point of view than we did.

Position of the Problem from Maxwell's Point of View—Outline of an Engineering Solution

According to a classification made by Steinmetz, we can say that the transients considered in electrical engineering are either simple time transients, as in machinery, or simple space transients, like voltage and current distribution along a transmission line under steady a-c. conditions, or both time and space transients, as in the case of a line under transient conditions. We have already noticed that the notion of space involved in these transients is unidimensional or depending on one space variable only (equation 1); this supposes implicitly that the electromagnetic field of these transients is in planes. We are led, therefore, to consider more extended classes of transients; three dimensional space transients, as occuring near the ends of a steady a-c. line or near a wireless c. w. antenna and time and three dimensional transients, when steady conditions in such systems are changing. The only means of studying such transients is to resort to Maxwell's equations of the electromagnetic field, connecting the electric force E and magnetic force H. From these equations, follows the same equation for E and H, *viz.*:

$$\frac{\epsilon\,\mu}{c^2}\frac{\partial^2 E}{\partial t^2} + \frac{4\,\pi\,\mu\,\gamma}{c^2}\frac{\partial E}{\partial t} = \frac{\partial^2 E}{\partial x^2} + \frac{\partial^2 E}{\partial y^2} + \frac{\partial^2 E}{\partial z^2} \qquad (2)$$

E and H are space vectors, C represents the velocity of light in vacuo, ϵ and μ are the numerical values of the dielectric constant and magnetic permeability of the medium and γ the conductance of the medium expressed in electrostatic units. In air, ϵ and μ are unity and γ zero; in conductors, ϵ is to be taken as zero. From (2) is shown that a disturbance, *i. e.* a local discontinuity of E or H is propagated in the medium at the speed $c: \sqrt{\epsilon\,\mu}$. Equation (2), of which (1) is a particular case, is the "damped wave equation," well known in mathematical physics. Although much work has been done on this equation even in electromagnetics, no solution has been obtained that seems directly available for the present problem, as far as we know. They generally deal with steady state sinusoidal waves along wires, without considering the source producing them, nor how they are initiated. (Sommerfeld, *Ann. Phys.* 67, 1899. Mie, Abraham, *Ann. Phys.* 2, 1900, Hondros. *Ann. Phys.* 1909, etc.) What we want is a knowledge of the whole electromagnetic field proceeding from a disturbance of voltage or current initially localized at a point of the line; the values of the field near the wires will give the amplitude and shape of the traveling wave, the values of the field at great distances from the line will give its radiation.

The mathematical difficulties involved in a general solution are indeed very great, but we believe that the position of the problem as it was sketched is the only one that can lead to a full answer to the question of the attenuation and distortion of traveling waves along wires.

We found it, however, possible to decide whether the radiation is of engineering importance in the attenuation of the waves, either traveling or stationary. By *radiation*, we mean, as usual, the constant limit S towards which tends the flow of energy, as defined by Poynting's theorem, through a sphere enveloping the whole electrical system, the transmission line in the present case, when the radius of the sphere is increasing above any fixed value. The time integral of the preceding limit S will be called the "total radiation" and denoted by W. We will show first that the classical theory of waves (neglecting radiation) gives a "theoretical" distribution of current along the line that is a very close approximation to the "true" distribution, *i. e.*, the unknown distribution taking place when the radiation is considered. Knowing the current in the line, one can calculate the corresponding radiation that must exist; an approximate value will be obtained by substituting the "theoretical" current for the "true" current. If, now, the amount of radiated energy is found to be quite negligible, say one to a hundred, compared to the joulian energy dissipated in the wires, we get an *a posteriori* proof of the rectitude of our premises, that is, that the true distribution of current, is given at, say, one per cent by the classical theory. As attenuation and distortion of the waves are produced by the dissipation of energy in the system, it is logical to conclude that the radiated energy, a cause hundred times less in magnitude than the energy dissipated by joulian heat, will produce a correspondingly small effect in attenuating and distorting the waves, *i. e.*, the radiation will be a negligible factor from an engineering standpoint.

The method is one of successive approximations, as used in experimental physics. It has already been used for calculating the steady radiation of given types of antennas, generally without being substantiated.

(Pierce, El. waves, Chapter IX. F. Cutting, *Proc. I. R. E.*, p. 129, 1922). In the case of a straight oscillator, Abraham found the present method in quantitative agreement with the more elaborate solution based on the full solution of Maxwell's equation. (*Phys. Zeit*, 2, p. 329, 1901). It is to be noticed that in the case of antennas, the radiation is the controlling factor and the joulian dissipation only secondary, while in the case of transmission lines the conditions are reversed. This strengthens our conclusions even more.

We first consider perfect conductors, and later take into account the influence of joulian losses.

When any kind of disturbance of current is propagated along a perfect thin wire, Heaviside shows how the corresponding electromagnetic field is set up by means of spherical traveling waves. (El. Theory, Vol. I, art. 54, etc., where what he calls the "motion of a charge" is entirely equivalent to the propagation of a "current along a wire.") The reflection of current and the corresponding electromagnetic field generated by spherical waves originating at the point of reflection are indicated. (in El. Theory, Vol. II, art. 393, 394.) This theory neglects the diameter of the wires, compared to the length of the disturbance. At that order of approximation, the current (or traveling wave) is propagated undistorted and unattenuated at the speed of light in the air, and reflected as usual, even with regard to possible radiation.

We thus take the distribution of current along the line, either a stationary or traveling sinusoidal one in the steady a-c. case, or a traveling rectangular one in the case of a sudden impulse.

Stationary Radiation from a Transmission Line

We mean the radiation that takes place under steady a-c. conditions by means of stationary waves, such as the natural oscillations of a line, without joulian losses.

Different modes exist, according to the terminal conditions to which the line is subjected. We consider, as an example, a line free at both ends, thus capable of half-wave length oscillations and multiples thereof.

We assume spherical polar coordinates, with the origin O_1 at the middle of the length l of the wire No. 1, and the polar axis $+ z$ along the same wire.

A length along the wires will be z, r_0 is the distance between a point P and the origin O_1, θ_0 is the angle between $O_1 P$ and the $+ z$ axis; r and θ are the same quantities referred to any point of the wires instead of to O_1; ϕ is the angle (longitude) that the plane $P\, O_1\, z$ makes with the plane of the wires, measured from the direction opposite to the second wire No. 2; d is the distance between the wires. (Fig. 1.)

The distribution of the current along wire 1 is from the preceding:

$$I = i \cdot \cos \frac{\pi\, n\, z}{l} \cdot \sin \frac{\pi\, n}{l}\, c\, t \qquad (3)$$

with $- l/2 \leq z \leq + l/2$, and with reversed sign for the current along wire 2. I is positive, if directed along $+ z$; n is an odd integer giving the "order" of the oscillation; c represents the velocity of light; i is the maximum current.

We have for the electromagnetic field due to the rate of change of a current element $I\, d\, z$, at distances large compared to the wave length of the oscillation, the values first given by Hertz under an equivalent form (*Wied. Ann.* 36, p. 1, 1889; or *Ausbr. Elekt. Kraft.*, p. 153, 1892).

$$E = H = 1/c \frac{\sin \theta}{r} \frac{d}{d\, t} (\hat{I}\, d\, z) \qquad (4)$$

where $I\, d\, z$ is the same as the time derivative of the moment of Hertz's doublet. $\hat{I}$ means I, where the time t has been replaced by $t - r/c$; the current I and magnetic force H are expressed in electromagnetic units; the electric force E is expressed in electrostatic units. At a point P, E lies in the plane of P and the wire, and is perpendicular to r; at the same point, H is perpendicular to this plane. The positive directions are shown on the diagram. We consider the whole transmission line as a large sum of such current elements. At the point P, the elementary H' s add themselves, but all the E' s do not fall in the same direction. They will do so, however, and will add, provided we recede far enough from the line, because all differences in direction then vanish, *i. e.* θ can be taken as a constant. We can write neglecting quantities of the second order, *i. e.*, $1/r^2$ as compared to $1/r$:

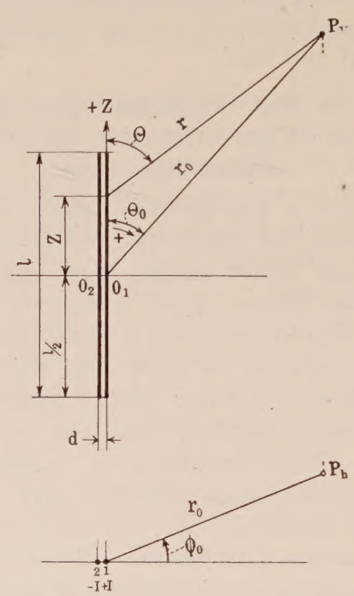

Fig. 1

$$E = H = 1/c \,.\, \frac{\sin \theta_0}{r_0} \,.\, \frac{d}{d\, t} \int_{-l/2}^{+l/2} (\hat{I}_1 - \hat{I}_2)\, d\, z \qquad (5)$$

where I_1 and I_2, the currents in the wires 1 and 2 are to be given their proper time phase $t - r/c$.

At great distances, we have with the same approximation

for wire 1 $\quad r = r_0 - z \cos \theta_0$

for wire 2 $\quad r = r_0 - z \cos \theta_0 + d \sin \theta_0 \cos \phi_0 \qquad (6)$

Still with the same approximation, and neglecting

the higher powers of d/l, which is of the order of 10^{-3} to 10^{-5}, (3) gives

$$\hat{I}_1 - \hat{I}_2 = i \,.\, \cos \frac{\pi\, n\, z}{l} \,.\, \cos \frac{\pi\, n}{l} (c\, t - r_0 + z \cos \theta_0) \,.\, \frac{\pi\, n\, d}{l} \sin \theta_0 \cos \phi_0 \tag{7}$$

In this expression, z cannot be neglected as compared with r_0, because these quantities figure as argument of the function cos. Substituting in (5), performing the time[4] derivation and the integration with respect to z, we get

$$E = H = (-1)^{\frac{n+1}{2}}\; 2\, i \,.\, \frac{\pi\, n\, d}{l} \,.\, \frac{\sin \frac{\pi\, n}{l} (c\, t - r_0)}{r_0} \cos \left(\frac{\pi\, n}{2} \cos \theta_0 \right) \cos \phi_0 \tag{8}$$

where n is an odd positive integer, and the signs agree with the assumed convention. This formula represents the steady electromagnetic field from an a-c.

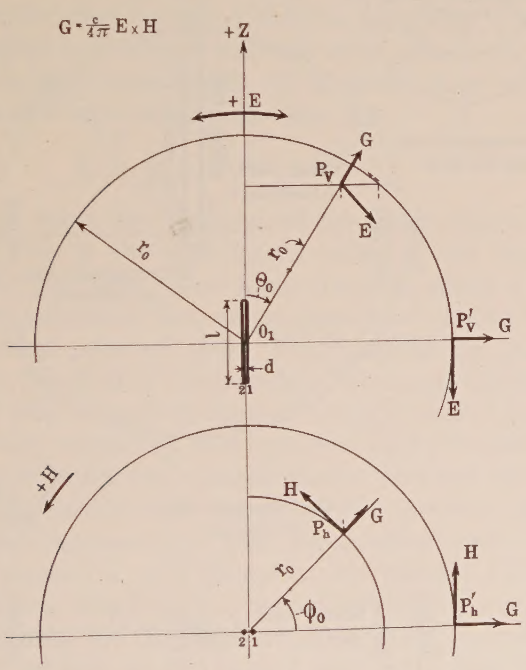

FIG. 2

transmission line of length l, at a distance r_0 from the origin so large that the ration l/r_0 is very small. The electric and magnetic forces E and H lie on pure spherical waves, traveling at the speed c from the origin on the line. We consider the intersection of the $+ z$ axis with a sphere as a positive pole (origin of the angles θ) of the sphere. Then, the electric force is directed along meridians and the magnetic force along parallels; the sign in formula (8) is in accordance with the original conventions. (Fig. 2).

The main difference between the "field of radiation" of a transmission line and that of a single wire line (antenna), is that, in the first case, the forces are only of the order of d/l, compared to the second case, which is very small.

4. See note 1.

It is seen that the electric and magnetic forces are perpendicular to the direction of propagation, (the radius of the sphere), as it must be in the case of pure transversal waves; and thus Poynting's vector $E \times H$ is perpendicular to the sphere. Hence, we have for the flow of energy or energy radiated per unit of time

$$S = \frac{c}{4\,\pi} \int E\, H\, d\, \Sigma \tag{9}$$

integrated over the area of the sphere of radius r_0, with $d\,\Sigma$ as element of area.[5]

Substituting the values (8) for E and H, and performing the integrations, and taking the time average, we obtain:

$$S = C \,.\, \pi^2/2 \left(\frac{n\, d}{l} \right)^2 . \; i^2 \quad \text{ergs/sec.} \tag{10}$$

or

$$= 15 \,.\, \pi^2 \left(\frac{n\, d}{l} \right)^2 I^2 = 15 \left(\frac{2\, \pi\, d}{\lambda} \right)^2 I^2 \text{ watts} \tag{11}$$

where I is here the maximum current in amperes and λ the wave length. The *power radiated* by an oscillating transmission line, open at both ends, is thus, for a given current, numerically *proportional to the square of the ratio of the distance between the wires to the wave length of the oscillation.*

We compare the power radiated to the power dissipated by heat, taking as an example the line whose constants are

No. 00 B & S
d = 183 cm.
l = 100 km.
Total d-c. resist. line = 48 ohms
Total external inductance = 0.238 henry

We have, for the power radiated S

for $n = 1$ $\lambda = 2 \times 10^7$ cm.
$S = 0.5 \times 10^{-7}$ watts per max. ampere
f = 1500 cycles/sec.

$n = 2001$ $\lambda \cong 10^4$ cm.
$S = 0.2$ watts per max. ampere
$f \cong 3 \times 10^6$ cycles/sec.

Due to the sinusoidal distribution of current, the power dissipated by heat is only 48/4 watts per max. ampere at low frequency; it is about 60 times more at three million cycles.

Thus, even at three million cycles, the power radiated by the line is only 1/60 or 1.7 per cent of the power wasted in heat at low frequency, or 1/3600 of the total heat wasted at three million cycles. *Hence, the radiation of oscillating transmission lines is entirely negligible in engineering practise.*

Dr. Steinmetz's formulas amounted to writing the radiated power proportional to $d\,.\,l/\lambda^2$ instead of d^2/λ^2.

Similar results are obtained in the case of forced oscillations of a line or impressed a-c. and load to Carson's formula. (JOUR. A. I. E. E., Oct. 1921, p. 789.)

Instead of considering an ideal sinusoidal current

5. See Note 2.

distribution along the line, as when there are no losses, we might introduce the actual distribution given by the hyperbolic theory. There would be only more complication in the integrations, but the order of magnitude of the result would remain the same, *i. e.* proportional to d^2/λ^2; thus quite negligible.

TRANSIENT RADIATION FROM A TRANSMISSION LINE

We mean the radiation that accompanies the production of traveling waves. When a disturbance of current is suddenly produced at the end O of a semi-infinite, thin, perfectly conducting wire, it is propagated in first and very close approximation as seen above, unattenuated and undistorted, at the speed of light, along the wire. The wire is supposed to be the only conductor in the empty space. The accompanying electromagnetic field is propagated, at sufficient distance from the source, by spherical waves, also at the speed of light. Its expression at a point P is, when r is great, *i. e.*, such as to make $1/r^2$ negligible compared to $1/r$:

$$E = H = \hat{I}/r \cdot \frac{1 + \cos\theta}{\sin\theta} \tag{12}$$

r denotes the distance PO; θ is the angle that PO makes with the wire; $\hat{I}$ the current at the origin O, given as a function of time t, where t has been replaced by $t - \frac{r}{c}$: c is the speed of light. I and H are expressed in electromagnetic units; E is in electrostatic units. I is positive when flowing along the positive direction of the wire. The electric force E is directed along meridians; the magnetic force H along parallels.

This formula is substantiated[6] by noticing that it verifies both Maxwell's equation for r large, and that for θ very small, it represents plane electromagnetic waves traveling at the speed c along an infinitely thin wire;

$$E = H = \frac{2\,\imath}{l} \tag{13}$$

with $l = r \sin\theta$ being the distance of a near by point close to the wire. When the traveling disturbance of current reaches the end of the wire, it can be absorbed by the terminal apparatus without reflection; this is equivalent to starting at the end a new disturbance $-\hat{I}$, of opposite sign, but of same direction of propagation as the first, so that each cancels the other along the wire supposed to be extended. If there is partial or total reflection, a new superimposed disturbance of current $K\hat{I}$ is supposed to be sent along the wire from the end towards the origin, thus propagating in opposite direction, the value and sign of K, which is the coefficient of reflection, depend on the terminal conditions.

We shall consider, just for simplicity, as only disturbance of current the sudden starting or stopping of a constant current at the origin, *i. e.*, "rectangular waves" of current. The stopping will be considered as the starting of a current of opposite sign, in the same direction of propagation.

The case of a *transmission line* reduces itself to the preceding case. We consider a line composed of two parallel semi-infinite wires originating in O_1 and O_2 and at the distance d apart. The coordinates used are the same as before, and are shown on the diagram, Fig. 3. A disturbance is produced at the origin, consisting of a suddenly flowing constant current $+I$ at O_1 and $-I$ at O_2. At *great* distances from the source, the

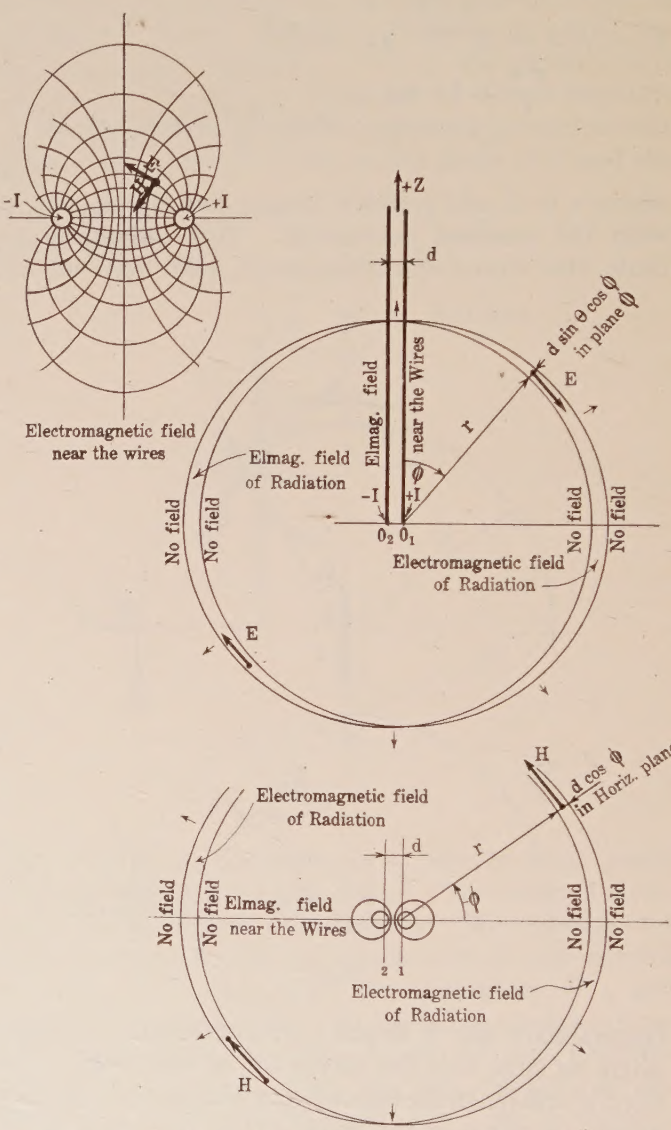

FIG. 3

electromagnetic field of the disturbance will be given by the sum of two expressions like (12) where due regard is given to the position of the sources O_1 and O_2 and their influence upon the "retardation" $t - \frac{r}{c}$, and also to the sign of the disturbances. This supposes that the presence of one thin wire does not interfere with the electromagnetic field of the other wire at great dis-

6. See Note 3.

tances; the linearity of the electromagnetic equations permits the addition of the fields.

When a sufficient time has elapsed after the disturbance started at the origin, *i. e.*, when its spherical front will have reached a great distance, in the sense we gave to that expression, the electromagnetic field of the disturbance can be considered as composed of two parts. (See Fig. 3.) One, in the space common to both "front spheres" O_1 and O_2, centered upon the sources O_1 and O_2; the other in the space between the two spherical surfaces, which can be considered as a very thin spherical shell of variable depth

$$d \sin \theta \cos \phi$$

this being equal to the distance $O_1 O_2$ projected in the direction considered (θ, ϕ). The electromagnetic field outside both spheres is obviously zero. In the shell, it is given by (12), with the proper sign for I, and lasts at a fixed point in the space during the time

$$| d/c \sin \theta \cos \phi |$$

the bars meaning an absolute value. Inside both spheres the electromagetic field is vanishing, *i. e.*, of the order of $1/r^2$, except near the wires where it is very nearly a plane wave field. It is given there by the difference of two expressions like (13)

$$E = H = \frac{2\,\hat{I}}{\rho_1} - \frac{2\,\hat{I}}{\rho_2} \qquad (14)$$

ρ_1 and ρ_2 being the distances of the point close to the wires. This is the well-known value of the electromagnetic field of a plane wave traveling along a perfect two-conductor line, as we considered it first from the classical point of view. Thus, besides the energy stored in the field of the traveling wave near the wires, there is also a small amount of energy present in the indefinitely expanding thin spherical shell of which we spoke, and which the classical theory does not account for. We consider this energy as the *transient radiation from a transmission line*, when acted upon by a sudden applied e. m. f. producing the current I in the line, because this energy is carried to infinity and thus is a net waste for the system. Its amount, calculated in a way entirely similar to that used in the case of the steady radiation above, is[7]

$$W = 3/2\, d \cdot 10^{-9} \cdot I^2 \text{ joules} \qquad (15)$$

where d is the distance between wires in cm. and I the sudden started constant current in amperes.

We consider as an example a *rectangular pulse* of current, *i. e.*, a traveling disturbance of constant current, extending over a length λ cm. The total waste by radiation will be twice as much as given by (15), because the same transient radiation occurs when suddenly stopping the current at the origin as when suddenly starting it. The total energy in Joules carried by the pulse along the wires, when it is far enough from the source, is given by $\dfrac{L\,.\,\lambda\,.\,I^2}{2}$ where L is the self induction in henries per cm. of the line, I the current in amperes. For the line already considered, L is equal to 23.8×10^{-9}. Thus the ratio of the radiated energy to the energy contained in the plane electromagnetic field of the pulse is given by

$$\frac{3\,d}{23.8}\, 1/\lambda = .126\, d/\lambda$$

or, for a pulse extending over a length λ one hundred times the distance d between the wires, only 0.1 per cent of the total energy of the pulse. It is to be noticed that the fundamental frequency of the pulse in this example is as high as 820,000 cycles. Taking as effective resistance the resistance at one million cycles (17.3 ohms per km. of line, Steinmetz loc. at p. 202), it is found that when the pulse travels only one third of its own length, it wastes in heat an amount of energy equal to the energy radiated. This shows how negligible is the effect of radiation.

When a rectangular wave of current reaches the end of a single wire, its stopping generates a new spherical

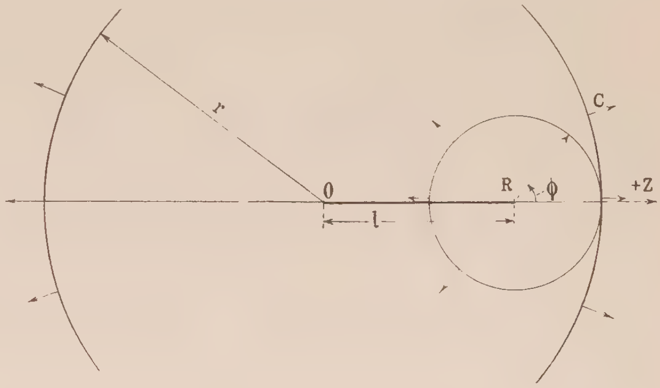

Fig. 4.

wave, expanding at the velocity of light and centered upon the end R; (Fig. 4) and which is tangent to the first spherical wave originating from O.

Similarly, in the case of a two wire line, a spherical shell of electric and magnetic field is generated, centered upon the two ends R_1 and R_2, and tangent to the first shell originating from O_1 and O_2. (Fig. 5.) Thus the total radiation will be the energy carried into infinite space by the two expanding spherical shells. As the two shells have the part $X_1 X_2$ partly in common, where their fields add to each other, the total energy radiated will not be exactly that obtained by adding the energies of both shells separately, but will be a little less. It is shown that taking this sum an error is committed that will not exceed the ratio of the angle $\dfrac{X_1 X_2}{r}$ to 2, *i. e.*, of the order of d/l,[8] or between 10^{-3} to 10^{-5} or less. Hence, to that approximation, we can say that *the starting current and successive reflections will each add a given amount to the energy lost by radia-*

7. See note 4.

8. See note 6.

tion. The solution of specific cases is thus directly given by the preceding. We give the following results as illustrations of the method.

1. The *sudden* establishment from one end of a line of a sustained continuous current I, without reflection at the other end, wastes

$$3\, d\, 10^{-9}\, I^2 \text{ joules} \tag{16}$$

by radiation; this result is independent of the length of the line or of its material; it depends only on the distance d between the two wires of the line. In this formula and in all the following, d is in centimeters and I in amperes.

Taking the same 100 km. transmission line as previously, and assuming only the d-c. resistance even during the transient conditions, it is seen that the energy wasted by radiation is only 1/10,000th of the energy wasted in heat during the time in which the line is being charged, and the steady d-c. conditions are reached. For a 1-km. line, the radiated energy would

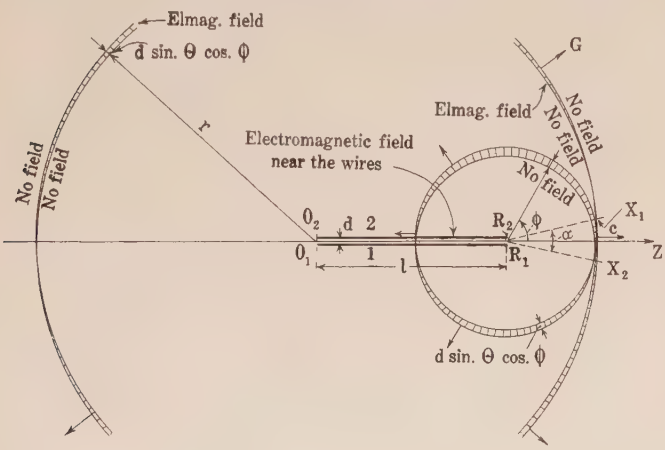

Fig. 5

still be only one per cent of the energy wasted in heat during the transient conditions. The same remark as to the order of magnitude of the radiation compared to the joulian losses applies to all following examples.

2. A total *reflection* of a "rectangular wave" of current I at an *open* end of a line radiates[9]

$$4\, d\, 10^{-9}\, I^2 \text{ joules;} \tag{17}$$

at a *grounded* end,

$$2\, d\, 10^{-9}\, I^2 \text{ joules.} \tag{18}$$

In general, we have a *partial reflection* when the amount of current $K\, I$, (in magnitude and sign), is reflected and thus the rest of the wave is absorbed in the terminal apparatus. The radiated energy there is given by

$$3/2\,(1 - 2/3\, K + K^2)\, d\, 10^{-9}\, I^2 \text{ joules} \tag{19}$$

of which the three preceding formulas are particular cases. ($K = 0, K = -1, K = 1$)

3. A complete transposition, *i. e.* a sudden rotation of 180 deg. of the plane of the wires of the line, produces a radiation of

$$6\, d\, 10^{-9}\, I^2 \text{ joules,} \tag{20}$$

or four times as much as given by formula (15), because a transposition amounts to a sudden stopping of the current plus a sudden starting of the same current with opposite sign, in the same direction of propagation or to a sudden starting of twice the same current in the same direction, with opposite sign.

Hitherto, we considered a current flowing suddenly in the line at maximum value or a "rectangular wave" as we called it. Any other law for the current as a function of the time at the origin, as for example a sinusoidal law, can be assumed, with only changes in the calculations, but yielding the same conclusions as to the magnitude of the radiation effect.

We also neglected the influence of the ground and supposed a transmission line isolated in space. A perfectly conducting ground can be accounted for by taking with the line its image with respect to the ground; the resulting radiation is obviously less.

If, instead of considering disturbances between the two wires of a line, we consider disturbances between line and ground, the distance d between the wires would have to be replaced by twice the height of the line above the ground, in the case of a good conducting ground. This can magnify the radiation effect about twenty times, but keeps it still negligible compared to the effect of heat dissipation in the conductors.

Conclusions

The present conclusions settle the question of the relative unimportance of radiation in the attenuation and distortion of traveling waves along lines. They, however, leave the way open for the investigation of other more important causes of attenuation and distortion, among which we suggest the transient penetration of the current into the wire at the front of the disturbance, as mentioned above; the dissipation of energy in the ground due to the fact that some lines of force of a two-wire transmission line reach the ground and cause an attenuation as in the case of wireless waves; the non-homogeneity of the transmission line for high-frequency waves, *i. e.*, the slight periodic variations that occur in the constants of the line due to presence of poles and curved spans. The influence of changes in direction in the line, as far as radiation is concerned, can be found by the method employed here and is negligible.

Summarizing

1. A criticism of the classical theory of propagation of traveling waves along a two-wire transmission line has been given showing that, as far as the shape of the wave near the front is concerned, this theory is still unsatisfactory.

2. Dr. Steinmetz's theory of the effect of radiation on traveling waves has been examined.

9. See note 5.

3. The position of the problem of radiation of lines has been sketched from Maxwell's electromagnetic point of view, in connection with the accepted engineering theories of transients.

4. An engineering solution of the problem is offered, showing that under steady a-c. as well as under transient conditions, *the effect of radiation upon electromagnetic waves propagating along transmission lines is quite negligible as compared to the effect of heat dissipation in the wires.*

The procedure used here in the case of steady a-c. conditions is to be considered an extension of a method due to Abraham;[10] it is different in the case of transients, and thought to be new.

5. Other possible causes of attenuation and distortion of traveling waves are suggested.

NOTE 1

The integration to be performed is obtained by substituting the time derivative of $\hat{I}_1 - \hat{I}_2$, given by (**7**) into (**5**); so

$$E = H = -\imath \frac{\pi n}{l} \cdot \frac{\sin \theta_0}{r_0} \cdot \frac{\pi n d}{l} \cdot \sin \theta_0$$
$$\cdot \cos \phi_0 \int_{-l/2}^{+l/2} \cos \frac{\pi n z}{l} \cdot \sin \frac{\pi n}{l} (c\,t - r_0 + z \cos \theta_0) \cdot d z$$

But

$$\sin \frac{\pi n}{l} (c\,t - r_0 + z \cos \theta_0) = \sin \frac{\pi n}{l} (c\,t - r_0) \cdot \cos \frac{\pi n}{l} (z \cos \theta_0) + \cos \frac{\pi n}{l} (c\,t - r_0) \cdot \sin \frac{\pi n}{l} (z \cos \theta_0)$$

The second term contributes nothing to the integration, for sin $\frac{\pi n}{l}$ $(z \cos \theta_0)$ changes its sign with z. We thus have only to perform the integration

$$\frac{\pi n}{l} \int_{-l/2}^{+l/2} \cos \frac{\pi n z}{l} \cdot \cos \frac{\pi n}{l} (z \cos \theta_0)\, d z$$
$$= \int_{-\frac{n\pi}{2}}^{+\frac{n\pi}{2}} \cos x \cdot \cos a\, x \cdot d x$$
$$= 1/2 \int_{-\frac{n\pi}{2}}^{+\frac{n\pi}{2}} \cos (1 + a)\, x \cdot d x + 1/2 \int_{-\frac{n\pi}{2}}^{+\frac{n\pi}{2}} \cos (1 - a)\, x \cdot d x$$

$$= \frac{\sin (1 + a)\, n\, \pi/2}{1 + a} + \frac{\sin (1 - a)\, n\, \pi/2}{1 - a}$$
$$= \frac{2}{1 - a^2} \cdot \sin \frac{\pi n}{2} \cdot \cos a \frac{\pi n}{2} \ (n \text{ odd})$$
$$= \frac{2}{\sin^2 \theta_0} \cdot (-1)^{\frac{n-1}{2}} \cdot \cos \left(\frac{\pi n}{2} \cos \theta_0 \right)$$

which, multiplied by the constant factors that we did not write through, gives formula (**8**).

NOTE 2.

The flow of energy S, given by (**9**), is

$$S = \frac{c}{4\pi} \int E\, H\, d\, \Sigma$$

integrated over the area of the sphere of radius r_0; the values of E and H are to be taken from formula (**8**), and $d\,\Sigma$ is the element of area in spherical polar coordinate, *i. e.*,

$$r_0^2 \sin \theta_0\, d\, \theta_0\, d\, \phi_0$$

We thus have to integrate

$$S = \frac{c}{4\pi} i^2 \left(\frac{2\,\pi\, n\, d}{l} \right)^2 \frac{\sin^2 \frac{\pi n}{l} (c\,t - r_0)}{r_0^2}$$
$$\int_{\theta_0 = 0}^{\pi} \int_{\phi_0 = 0}^{2\pi} \cos^2 \left(\frac{\pi n}{2} \cos \theta \right) \cos^2 \theta_0 \sin \theta_0\, r_0^2\, d\theta_0\, d\phi_0$$

But we have, dropping unnecessary indices,

$$\int_0^{2\pi} \cos^2 \phi \cdot d\, \phi = \pi$$

and

$$\int_0^{\pi} \cos^2 \left(\frac{n\,\pi}{2} \cos \theta \right) \sin \theta\, d\, \theta = 1$$

The double integral thus reduces to $\pi\, r_0^2$ and the value of S becomes

$$S = c\, i^2 \left(\frac{\pi\, n\, d}{l} \right)^2 \sin^2 \frac{\pi n}{l} (c\,t - r_0)$$

of which the time average is given by replacing $\sin^2$ by 1/2. Hence formula (**10**)

NOTE 3.

The equations (**12**) for E and H can be substantiated by proving that they satisfy both Maxwell's equations for r large, *i. e.* when $1/r^2$ is negligible compared to $1/r$. Maxwell's equations are, in air

$$1/c \frac{\partial E}{\partial t} = \text{curl}\, H$$
$$-1/c \frac{\partial H}{\partial t} = \text{curl}\, E$$

where E and H are space-vectors, E being expressed in electrostatic units and H in electromagnetic units.

The component of the curl of a vector, at a given point, in a given direction is defined as the line integral of that vector taken around a unit area located at the given point, of which the positive normal coincides with the given direction.

10. *Phys. Zeitschrift*, **2**, p. 239, 1901.

The curl components of E and H in the direction of the radius (see Fig. 3) are seen to be zero or of the second order, (*i. e.*, of the order of $1/r^2$), thus negligible. The components of curl E along a meridian line, and of curl H along a parallel line are obviously zero, because the vector is then perpendicular to the line of integration.

The component of curl H in the positive direction of a meridian line, (*i. e.*, towards the increasing θ), is given by

$$\text{curl}_\theta\, H = \frac{-H(r+\Delta r)\,.\,(r+\Delta r)\sin\theta\,.\,\Delta\theta + H(r)\,.\,r\,.\,\sin\theta\,.\,\Delta\theta}{\Delta r\,.\,r\sin\theta\,\Delta\theta}$$

where $H\ (r)$ means the scalar value of H at the distance r. But we have, neglecting quantities of the second order, and using the value of H given by (1):

$$H\,(r+\Delta r) = H\,(r) + \frac{\frac{\partial \hat{I}}{\partial r}}{r}\,.\,\frac{1+\cos\theta}{\sin\theta}\,.\,\Delta r$$
$$= H\,(r) - 1/c\,\frac{\partial E}{\partial t}\,.\,\Delta r$$

Substituting in $\text{curl}_\theta\, H$, at the same approximation, we find the first equation of Maxwell.

The same procedure with regard to the signs leads to the second equation of Maxwell.

NOTE 4.

Formula (**15**) represents the energy carried to infinity by the spherical shell of variable depth

$$d\sin\theta\cos\phi$$

in which the value of the electromagnetic field is given, for $-\pi/2 \leq \phi \leq +\pi/2$, by formula (**12**)

$$E = H = \hat{I}/2\,.\,\frac{1+\cos\theta}{\sin\theta}$$

where I is the constant value of the suddenly impressed current. For $\pi \geq \phi \leq \frac{3\pi}{2}$, the sign of both E and H is to be changed.

At a given point on the sphere of (large) radius r, this electromagnetic field lasts during the time

$$|\,d/c\sin\theta\cos\phi\,| \qquad (c \text{ speed of light})$$

the bars meaning a quantity that is positive.

The total energy radiated W will be given by the time integral extended over the sphere of radius r of Poyting's vector, which is directed everywhere along the radius outwards the sphere; *i. e.*

$$\frac{c}{4\pi}\,E \times H\,|\,d/c\sin\theta\cos\phi\,|$$

integrated over the sphere of which the element of area is

$$r^2\sin\theta\,d\,\theta\,d\,\phi$$

We thus have to perform

$$W = \frac{c}{4\pi}\,I^2/r^2\int_{\theta=0}^{\pi}\int_{\phi=0}^{2\pi}\left[\frac{1+\cos\theta}{\sin\theta}\right]^2.$$
$$|\,d/c\sin\theta\cos\phi\,|\,r^2\sin\theta\,d\,\theta\,d\,\phi$$

But we have

$$\int_0^{2\pi}|\cos\phi\,|\,d\,\phi = 4$$

and

$$\int_0^{\pi}[1+\cos\theta]^2\,d\,\theta = \int_0^{\pi}(1+2\cos\theta+\cos^2\theta)\,d\,\theta$$
$$= \pi + 0 + \pi/2 = \frac{3\pi}{2}$$

The value of W is thus

$$W = 3/2\,d\,I^2 \qquad \text{elmag C. G. S. units}$$

which is equivalent to (**15**).

NOTE 5.

The total reflection "with change of sign" of a rectangular wave of current at the free end of a line can be considered as the result of the stopping of the incoming wave $+I$ at the end, by starting at the end a new wave $-I$ along the same direction of propagation as that of the incoming wave, plus starting a new wave $-I$ in the opposite direction, *i. e.*, back into the line. This last wave is the wave "reflected with change of sign." The sign of a wave bears no relation at all to the direction of propagation.

The reflection at a free end of a line is thus equivalent to starting simultaneously two waves $-I$ from the end in two opposite directions. The electromagnetic field of such a double disturbance along a single wire is easily deduced from that given in formula (**12**), for a single disturbance. It is, with regard to the signs

$$E = H = \frac{(-\hat{I})}{r}\,\frac{1+\cos\theta}{\sin\theta} + \frac{(-\hat{I})}{r}\,\frac{1-\cos\theta}{\sin\theta}$$
$$= \frac{(-2\,\hat{I})}{r}\,\frac{1}{\sin\theta}$$

$(-I)$ is the current started in both directions at the free end, equal in absolute value to the incoming current, and where the time t, of which I is a function in the general case, has been replaced by $t - r/c$, r being taken from the free end.

The case of a two-wire (transmission) line reduces to the preceding one as was seen. Thus, in the case of a rectangular wave of current along a line, the elec-

tromagnetic field due to the sudden starting at the end of the line of a current $(-I)$ in both directions is:

$$E = H = -\frac{2\,\hat{I}}{r}\,\frac{1}{\sin\theta}$$

This field exists in a spherical shell of variable depth, $d \sin\theta\cos\phi$, expanding at the speed of light, as it has been shown. It lasts at a fixed point in space during the time

$$|\,d/c \sin\theta\cos\phi\,|$$

the bars meaning a positive quantity. The amount of radiated energy W can be found exactly as in the preceding note. We have:

$$W = \frac{c}{4\pi}\,\frac{4\,I^2}{r^2}\int_{\theta=0}^{\pi}\int_{\phi=0}^{2\pi}\frac{1}{\sin^2\theta}\,|\,d/c\sin\theta\cos\phi\,|\; r^2\sin\theta\,d\theta\,d\phi$$

what reduces immediately to:

$$W = 4\,d\,I^2 \qquad \text{elmag c. g. s. units}$$

which is equivalent to formula (**17**).

In general, when the amount of current $K\,I$ (in sign) is reflected into the line, the rest being absorbed in the terminal apparatus, we have for the electromagnetic field, with regard to the sign,

$$E = H = \frac{-\hat{I}}{r}\cdot\frac{1+\cos\theta}{\sin\theta} + \frac{(K\,\hat{I})}{2}\cdot\frac{1-\cos\theta}{\sin\theta},$$

which exists in a spherical shell of variable depth.

$$d\sin\theta\cos\phi$$

expanding at the speed of light.

The radiated energy is, as above,

$$W = \frac{c}{4\pi}\,I^2/r^2 \int_{\theta=0}^{\pi}\int_{\phi=0}^{2\pi}\left|\frac{(1-K)+(1+K)\cos\theta}{\sin\theta}\right|^2 |\,d/c\sin\theta\cos\phi\,|\; r^2\sin\theta\,d\theta\,d\phi$$

The value for W follows

$$W = 3/2\,(1 - 2/3\,K + K^2)\,d\,I^2 \text{ elmag. c. g. s. units}$$

which is equivalent to (**19**).

NOTE 6.

The position of the point X_1, limiting the length X_1X_2 (Fig. 5) along which the two spherical shells can have parts in common is determined by the intersection of a circle of radius r centered upon O_1, and of a circle of radius $r - l$ centered upon R_2, r being very large compared to l. This allows to approximate the circles by parabolas of the same curvature, *i. e.*, of which the parameter p is equal to the radius of the circles; the axis of the first parabola will coincide with the wire O_1R_1, the axis of the second with the wire O_2R_2. We so have

$$y - d = \sqrt{2\,(r - l)\,x} \qquad \text{Par. 2}$$

$$y = \sqrt{2\,r\,x} \qquad \text{Par. 1}$$

with obvious axis of coordinates. Calling $(\xi_1\,\eta)$ the coordinates of the point X_1, we deduce

$$\eta = \sqrt{\frac{r}{r-l}}\cdot\sqrt{2\,(r-l)\,\xi} = \sqrt{\frac{r}{r-l}}\,(\eta - d).$$

As ξ is very small, η is the distance of X_1 to wire 1— We have thus, from the preceding equation, neglecting the square and higher powers of r/l:

$$\eta/r = 2\,d/l\,.$$

which proves that, viewed from a point of the line, the length X_1X_2 does not cover an angle larger than $\frac{4\,d}{l}$, provided l is small compared to r.

Hence, calculating the energy radiated by the two spherical shells in contact as if they were not in contact, *i. e.*, integrating over π instead of π minus the angle η/r, will introduce only an error of the order of d/l, thus quite negligible.

OXIDIZED KEROSENE AS A FUEL

The Department of Chemical Engineering of the Carnegie Institute of Technology has been conducting a series of tests to determine the relative merits of various oils as usable fuels. The completion of this important work should go a long way toward solving the problem of oil conservation, by the possible development of a new fuel.

According to Dr. J. H. James, head of the department conducting the experiments, oxidized kerosenes cause less "knocking" tendencies than straight kerosene when used in a kerosene engine. The tests also showed that oxidized kerosenes have approximately the same power development as ordinary kerosene, in spite of the fact that their thermal value is one-eighth less. Dr. James attributes the efficiency of the oxidized kerosenes to the better "clean up" in the combustion of these partially oxidized fuels.

The success of the experimental work at Carnegie at this stage gives promise that oxidized kerosene, which is manufactured by catalytic oxidation from low grade petroleum, may become a useful fuel in the future. Its properties may cause it to be used industrially in kerosene engines or blended with gasoline for use in gasoline engines. Although it has a somewhat lower fuel value than ordinary kerosene, one of the most favorable features of its effectiveness is that it undergoes much better combustion in the internal combustion engine.

Expansion of Oscillography by the Portable Instrument

BY J. W. LEGG
Associate, A. I. E. E.
Westinghouse Electric & Mfg. Co.

THE oscillograph has emerged from the obscurity of scientific laboratories and from the test departments of great electrical industries so that today it is occasionally seen on a rapidly accelerating elevated train, in a soaring air-plane, in a destroyer dashing through a rough sea, on the polished top of a conference table, and, in each case, operating as perfectly as though it were in a well-equipped laboratory.

In order that the oscillograph may act properly in these new surroundings and respond favorably to the touch of new masters, who have not received extensive training in the art, it was necessary not only that the outfit be transformed into a portable instrument but also that it should be more complete in its equipment, more permanent in its adjustments, more reliable in its results and quite independent of power supply.

The outfit described in the JOURNAL of July 1920 was the first big advance made towards a portable, *commercial oscillograph.* This outfit contained the essentials of a portable instrument but fell short of the mark because the construction of one outfit would not warrant a completely new design of incandescent lamp, transformer, control switches, and other parts which would be prohibitively costly except when made in some quantity.

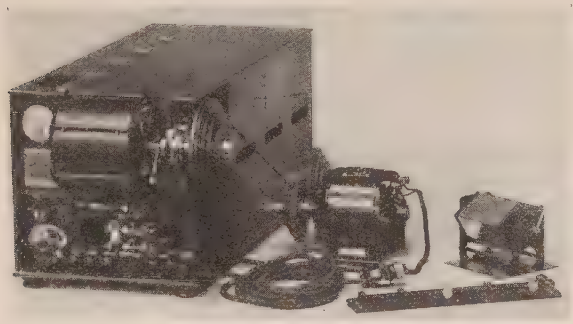

FIG.—GENERAL ASSEMBLY VIEW OF COMPLETE INSTRUMENT, SHOWING FILM HOLDER AND A-C. MOTOR ATTACHED, VIEWING MIRRORS AND SHUNT, AT RIGHT

This first outfit proved to be so successful, proved that its novel features were a financial asset, opened up so many new fields of oscillograph work that a foreign and domestic demand was established for additional outfits. This made it possible to re-design the oscillograph along the same general principles, but by specially designing nearly every part, it was possible to reduce the total bulk fifty per cent. At the same time new features were added, refinements were made, the case was constructed wholly of micarta, and the outfit became an instrument.

This instrument is *complete in one unit,* 11 inches wide, 11½ inches high and 25 inches long, except for the film holder and driving motor. See Fig. 1, and Fig. 2. The optical system and the vibrating system, of the three-elements, are no different in principle from that of predecessors using the instantly responding moving-coil galvanometer.

The internal equipment is so complete that the oscillograph may be used to study the recurrent or transient phenomena of almost any commercial or laboratory circuit without additional external resistors. The exception to this is the 3000-volt d-c. railway circuits, those operated from high-voltage rectifiers, etc. In such cases a water-tube resistance has been used up to over 100,000 volts.

Like the first portable outfit described, this instrument utilizes the great intrinsic brilliancy of an *incandescent filament on momentary abnormal voltage.* This intense light is focused on the tiny vibrating mirrors,

FIG. 2—ELEMENT-CONTROL AND LAMP-HOUSE SIDE OF OSCILLOGRAPH

of the three elements of the galvanometer, so that the reflected beams may give three instantaneous records of current, or voltage, on a photographic film passing at right-angles to the vibrating beams. The shutter mechanism, which gives but a single revolution exposure to the film, is mechanical in its action, and in closing knocks open the lamp switch, thus preventing the early destruction of the filament.

As was the case with the first outfit, this instrument is designed to be supplied from any lighting or power circuit of 110 or 220 volts at 25, 50 or 60 cycles.

An additional feature of this instrument is that it is designed to *operate from any standard 6-volt storage battery,* such as is used in automobile starting and lighting, by the substitution of a small shunt motor in place of the back-geared induction motor regularly supplied. The more constant speed of the a-c. motor and the more constant potential supplied to the lamp from the secondary of the transformer, make the a-c. operation more desirable. The 6-volt battery operation is used

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only where no a-c. is available as would be the case with a test on a moving electric car.

The operator may quickly change from correct connections for a-c. operation of lamp, trip-magnet, motor, etc. to 6 volt d-c. operation.

d-c. This element will give nearly 3 inches deflection on a 100-millivolt shunt. This makes it possible to use a standard meter-shunt, when taking slow films, and thus obviates carrying a 500 millivolt oscillograph shunt for tests on huge reversing motors, etc. The

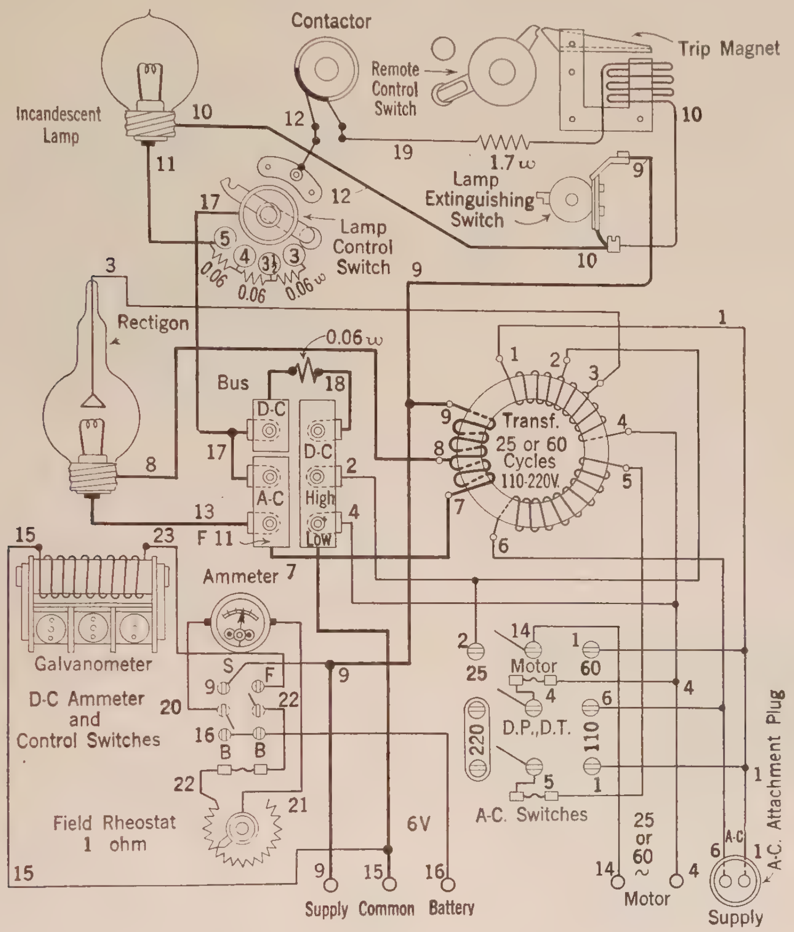


Fig. 3—Diagram of Supply Circuit for Lamp, Motor, etc.

A complete *diagram of circuits* and a key for operating the same is moulded into the inside surface of the element-control panel-cover. This is shown in Fig. 3.

The three complete sets of *element resistors* and dial switches (Fig. 2) are extremely convenient for adjusting the elements so as to give any desired deflection. The upper dial, of each set, has a range from 0 to 100 ohms for e. m. f. below 10 volts and for use as a deflection adjuster when the element is used, with a shunt, as an instantaneous ammeter. The lower dial is used to limit the deflection when it is desired to record the instantaneous values of e. m. f. above 10 volts. This dial has a range from 100 to 10,000 ohms. This permits the recording of a d-c. e. m. f. of 3000 volts, peak. Since the sensitivity of the standard element is 0.10 ampere per inch deflection, this would mean a 3 inch deflection on the ground glass, or on the film. The *super-sensitive element* requires but 0.02 ampere per inch deflection and hence will give about 3 inches deflection, with 10,000 ohms series resistance, on 600 volts, super-sensitive element will not respond to as high frequencies as the standard element. The former has a natural period in air of approximately 3000 cycles per second, while the standard element has a natural period of approximately 5000 cycles, at usual tension and

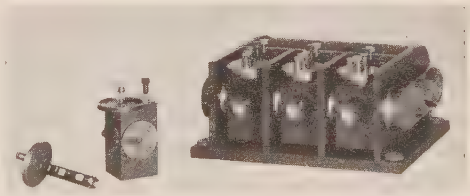


Fig. 4—Three-Element Galvanometer. Separate Element and Cell to One Side

sensitivity. The ultimate tensile strength of the vibrator ribbons is very high (approximately 160,000 pounds per sq. inch) and hence permits a greater tension on the ribbons when it is imperative to have a higher natural period, at a sacrifice in sensitivity.

The refinements in the *three element galvanometer*, Fig. 4 have made it most reliable. The overall dimensions have been reduced and the test increased to over *10,000 volts between each element*. The increase in sensitivity is not due to sacrifice in natural period but to the efficient design of the magnetic system.

The novel method of controlling transients, on the first portable outfit, proved to be so reliable that it was incorporated in the final instrument. Further advantage was taken of this method by designing a daylight-loading film-holder. Such would have been useless with former controls, which do not place the transient on a predetermined part of the film, for the daylight-loading roll-film cannot cover the full circumference of the rotating drum.

Film Holder

The daylight-loading film-holder, Fig. 5 is the latest development of the whole outfit and now operates reliably with all standard No. 3-A "Kodak" roll-films. The novel features of this film holder proved to be most satisfactory. A light- tight door in the stator gives access to two doors in the rotor. One rotor-door carries the unexposed film-spool, between clips. This door is snapped in place with the unexposed film within the rotor. The initial opaque paper is drawn two-thirds the way around the rotor and its end inserted in the empty spool which is to receive the exposed film. The second inner door is then closed and the stator door also. By the simple twist of a cap, as it is removed, the rotor may be locked in proper position for turning the spool, by an external winding-key. To perfect the action of this film-holder, it was found necessary to turn the spool so as to reverse the curvature of the film and thus keep the film, as well as the opaque paper, tight on the drum. The exposure number, on the opaque paper of the standard film, may be observed through the opening in the stator and rotor made by the removal of the cap. After each setting of the film, the cap is replaced and the rotor is free to turn at any speed desired. After the oscillogram has been taken, the cap is again removed and the film turned to position for the next exposure. The rotor is 4¾ inches in diameter and is so designed that the film comes very close to the optical slot of the main oscillograph case. This permits a much greater angle of convergence of light from the cylindrical condensing-lens. This has made possible an optical efficiency 250 per cent of that of former outfits. With a standard No. 3-A (3¼ in. x 5½ in.), 6 exposure, roll-film, one may take six oscillograms 3⅝ in. wide and 5 in. in effective length, or three oscillograms 10 in. in effective length. The total length of film after cutting, is more than eleven inches, for the standard oscillogram. Thus prints are correct in length for filing with standard 8½ in. x 11 in. report paper.

Fig. 5—Rotating Viewing, Mirrors and Daylight-Loading. Rotating Film Holder.

Viewing Attachment

A rotating-polygon of mirrors, Fig. 5, is added to the outfit for viewing recurrent a-c. phenomena. The mounting of these mirrors is so designed that they are operated from the standard driving-head at the proper speed to cause the waves to float slowly by, or stand still, as the tension on the belt of the induction motor is slackened. Since the incandescent lamp requires no attention, and since the optical efficiency of this instrument has been increased 150 per cent over former outfits, it is possible to operate this visual attachment continuously (without attention) and observe any chance momentary change in wave-shape, due to harmonics introduced to the line. The waves are so bright that several people may observe them at the same time, in an undarkened room. A mirror may be placed above the attachment at 45 deg. and thus shift the plane of vision from the vertical to the horizontal. These features make the attachment particularly valuable in classroom work.

For commercial work the photographic record is always required. The simplicity of operation, with the incandescent lamp and daylight-loading film-holder, makes it easy for the student, as well as for a trained operator, to take oscillograms. An oscillogram must always be taken to show transient (non-recurrent) phenomena. With this instrument it is very easy to obtain excellent records of transient phenomena, well spread out on the film.

Photographic Operation

The general scheme of photographic operation is best understood by reference to the diagram, Fig. 3. For actual construction see Fig. 1 and Fig. 6 The *contactor*, on the film driving-head, is set so as to operate the *trip-magnet* a fraction of a revolution ahead of the opening of the *mechanical shutter*. This fraction of a revolution is timed to be equal to the lag in operation of the remote controlled apparatus. (The setting of this contactor is immaterial when recurrent a-c. phenomena are being photographed). The *lamp-control switch stop* is set at the 3½, 4 or 5-volt position for slow, medium or fast films, respectively. The control switch is first brought up to the 3-volt position, allowing the lamp to come up to normal brilliancy and is then thrown against the stop. This makes a connection through the contactor to the

trip-magnet thus operating the *remote-control switch.* After the remote control, of the apparatus under test, has started to function, the shutter opens at the beginning of the active film. The transient starts, immediately afterward, and makes its record on the film, by the proper functioning of the galvanometer and optical systems. One revolution after the shutter opens, it

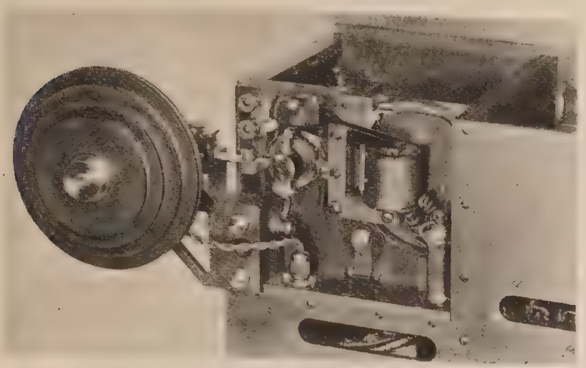


Fig. 6—Driving Head, Shutter Mechanism, Remote-Control Switch, and Lamp-Extinguishing Switch

closes and knocks open the *lamp-extinguishing switch,* thus saving the lamp for hundreds or thousands of such operations. Thus the lamp may be on 3½ volts for many minutes taking a slow film, or may be on 5 volts for 0.02 second when taking a film running at a speed of 1000 feet per minute. (0.005 sec. per inch). A good film can be taken, of 60-cycle waves, with the film running at 1300 feet per minute, using the incandescent lamp and the induction motor, in the second belt position.

Motor

The instrument is supplied with an *induction-motor* for driving the photographic-film and viewing-mirrors. This gives most satisfactory results equipped, as it is, with step pulleys and back gears. For any one belt

Fig. 7—Six-Volt Shunt Motor with Field Rheostat and Pulleys for Operating Film on Isolated Tests

position, the *film speed is very constant* and can be relied upon to within a fraction of one-per cent, when operated at a given frequency of supply. Where no a-c. supply is available it is easy to obtain a *small six-volt shunt-motor to operate the film.* Fig. 7 shows such a motor equipped with step pulleys and a field rheostat. The field is normally supplied with 6 or 12 volts and the armature with 2 or 6 volts, depending on the range of speed desired. An additional pulley may be supplied to go on the end of the a-c. motor-shaft so the backgears may be used for great reductions in film speed. This is convenient for *studying actual operating conditions* of electric elevators, subway trains, steel-mill motors, etc. This range of 0.2 foot per minute to over 1000 feet per minute, film speed, covers practically all requirements for the standard film and is a big advance over previous outfits.

A detailed description of the shutter mechanism and of the variable shunt (with a range of 20 to 1000 amperes continuous and 25,000 momentary) will not be repeated here since it would be the same as for the original outfit.

Long Film Attachment

A slow-speed, long film, daylight-loading attachment, Fig. 8 has been developed for certain fields of works. This is readily attached to the standard outfit and makes it possible to take any number of oscillograms, 58 inches in length, *without resort to a darkroom.* The film speed is remarkably constant over the whole length. On the first test-run, a slow belt-

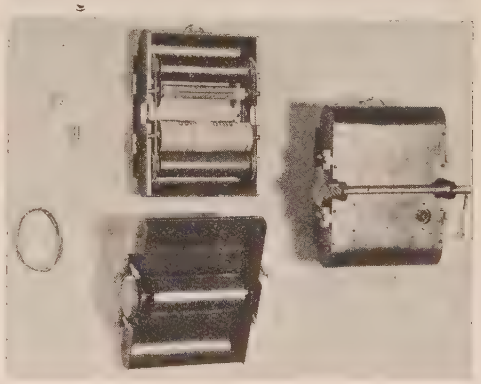


Fig. 8—Low-Speed, Long-Film Holder, Opened Up and Assembled

position, and the back-gears of the induction motor, were used to give a total exposure of over five minutes. With the belt tight, the record was so uniform that each individual cycle could be counted on a 25 cycle wave, even though they were less than one hundredth of an inch apart. This special holder was repeatedly loaded and unloaded on a destroyer while the latter was rolling and pitching as it plowed through a stormy sea.

This film-holder is quite novel in its *operation.* A standard 10 exposure #3-*A* "kodak" film is used. Split, flanged pins are plugged into the ends of the spools so these extensions fit into vertical slots in the holder with the unexposed film below a main driving drum, 1½ inches in diameter. The film raps half way around this drum and is wound up on another spool just above. Two rollers, one below the unexposed spool and one above the exposed spool, are drawn tight against the

opaque paper, on the spools, by flexible (spiral-spring) belts working in pulleys beyond the ends of each roller. The lower roller tends to hold back the unexposed film while the upper roller ensures the proper winding of the exposed film. Due to the fact that the upper pulleys are slightly smaller than the lower pulleys, all creepage is compensated for, and the film keeps the same peripheral velocity as the one driving drum. A red observation window permits the operator to note the numbers on the film as the exposure progresses. The holder is easily loaded and unloaded on the oscillograph without fogging the film. The films may be developed by any photographer or by the operator at his convenience, either in a dark-room or in a "kodak" tank-developer. This film holder is much better for low-speed work than the standard rotating-drum, as it gives nearly six times as long a record and thus shows up the details of operation of reversing-motors, electric trains, electric-arc furnaces, maneuvering of submarines, etc. Long films have been taken with a total time of 45 minutes. This may be made still greater if the case demands.

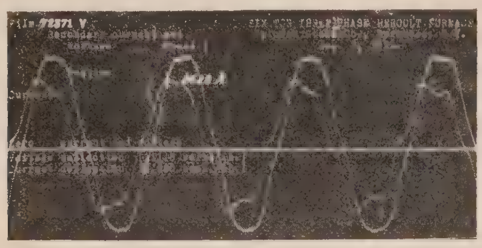


Fig. 9—Typical Oscillograms Taken with Portable Instrument

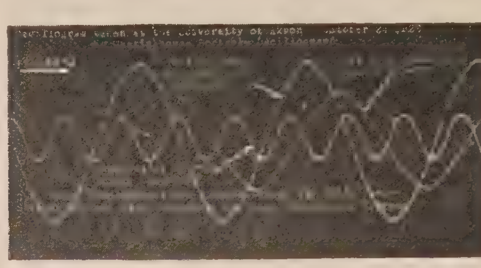


Fig. 10

Ventilation

Even though the various parts occupy a very small space adequate ventilation is provided. The resistance units are wound on thin cards of micarta so as to be very nearly non-inductive and so as to present a relatively great radiating surface. Over 1700 square inches of radiating surface is provided for the 30,000 ohms of resistance. Openings below and above these cards allow good circulation of air. Practically the only continuous operation that they would be subjected to would be the voltage from the secondary of a potential transformer. This would mean but 10 watts per element resistor. At ten times this input no appreciable heating is noticed.

The galvanometers in the first units were of an improved electromagnet type and were very satisfactory for an electromagnet equipment, occupying less space, consuming less energy and being insulated for a higher voltage between elements than any previous 3-element unit. The very latest developments, however, have brought out a superior magnet, of a *permanent* type, *which gives even better sensitivity* to the same vibrator elements, and eliminates: the field coil, rheostat, ammeter, battery, rectifier, bus-bars, etc., which were formerly required for the electromagnet galvanometer. This simplifies the diagram shown in Fig. 3 and greatly improves the instrument. These features insure cool operation of the damping fluid in the vibrator well and thus minimize the errors due to a change in viscosity of the damping liquid. This cool operation, together with the fact that the walls of the wells are made of micarta (with no coloring matter), minimizes discoloration of the damping fluid and thus prolongs the optical efficiency without attention.

Automatic Operation

Any number of these instruments may be operated *simultaneously*. Each oscillograph may be in a different substation and show the local effect of the same short-circuit. The novel features, of this instrument make it possible to connect its supply (for motor, lamp and trip-magnet) to a quick-acting relay, in the secondary of a current transformer in a high-voltage power-system, so that the oscillograph will function perfectly on a *chance short-circuit* (or heavy over-load). The record will show the unreduced value of the short, the arcing voltage, the current interrupted by the breaker and the restored line conditions. This remarkable action is made possible by the automatic, quick-acting features of this oscillograph. With no series resistance in the lamp circuit, the filament will come up to abnormal brilliancy in less than one-tenth of a second due to the great initial rush of current through the filament (the cold resistance of the filament being less than one-tenth the hot resistance). The lamp-extinguishing switch is re-connected, for automatic operation, so that it breaks the supply circuit, at the end of the exposure, and thus cuts off the motor, lamp and trip-magnet.

New Fields of Oscillograph Activity

From the foregoing description of the new instrument it is easily seen that only a few of its many new possibilities have been utilized. Engineering schools may use such an instrument to solve the many problems arising in small electrical industries, in the mills of the district, in the local electric power plants and transmission lines. This would be good training for post-graduate students and might result in lessening the financial burdens of the institution.

The whole outfit, Fig. 1, may be taken on a Pullman car in a special carrying case (for the main unit) and a handbag (for the motor, film-holder, viewing mirrors and shunt). An operator, assisted at times by the local porter, may personally conduct the outfit to almost any part of the country. A lower Pullman berth gives ample room for both operator and outfit. This is in considerable contrast to the bulk of express crates required to properly transport any previous, truly commercial, oscillograph outfit. In addition to its portability, its independence of any source of power supply greatly increases its range of operation, and its complete independence of a dark room makes its application still more simple. Such features enabled an operator to take two-hundred oscillograms in two days without changing a single optical adjustment. In another case an operator set up the apparatus in an electric car, in a distant city, and took over three dozen oscillograms in one day. The apparatus was set up in the morning with suitable switches to give a score of different combinations of current and voltage, without cutting off the power from the car. Calibrations were made and then the car was put through many maneuvers, in and out of thick traffic. Oscillograms were taken while the car was at full speed, during reversing, braking, acceleration, heavy overload, short-circuit, etc. Each record was of a transient condition and most of the records were made when the car was jerking or jolting, yet the records were as undisturbed as though they were made in a quiet laboratory. Not a single film was developed until after the outfit had been removed and the car put back into service, yet there was not a poor record in the lot, as far as the oscillograph was concerned. During the whole test the outfit was supplied by a battery borrowed from the starting and lighting system of an automobile.

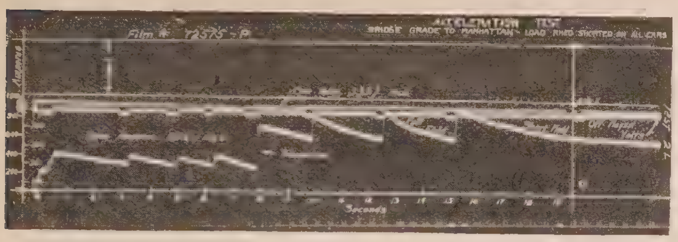


FIG. 11

The problems which are studied with an oscillograph are not always fundamentally electrical. Many purely mechanical movements can be detected and studied only through the medium of electricity and the oscillograph. Undesirable vibrations in machinery, noises, minute movements, momentary pressures, disturbances in the atmosphere, properties of materials and many other non-electrical functions have been studied with the oscillograph. Force or movement has to be transformed into a change in electric current through the medium of the carbon microphone, a special generator, a varying capacity or reactance, or the action of the piezo-electric crystal. The resulting current may be recorded directly by the oscillograph, or first amplified to suitable strength by the three-electrode vacuum tube. It is necessary to study these mechanical problems under operating conditions, and usually far from any electrical laboratory.

The instrument makes easy the solving of inductive interference troubles in distant telephone lines, and, in fact, makes it easy to study the actual conditions under which any piece of electrical apparatus is operating no matter whether that apparatus is in a well equipped laboratory or in some other part of the country, far from any laboratory convenience.

SUMMARY OF THE SPECIAL FEATURES OF THIS OSCILLOGRAPH INSTRUMENT

1. Complete in one micarta case, 11 x 11½ x 25 inches over all, except for film holder and motor.
2. May be supplied by 110 or 220 volts at from 20 to 70 cycles a-c., or from a 6 volt storage battery, for field operation.
3. Shutter mechanism and remote control switch which place transient phenomena on desired part of fast film.
4. Improved optical efficiency and an incandescent lamp illuminant, operated at momentary abnormal voltage, so as to take fast oscillograms.
5. Included transformer, for supplying lamp and motor.
6. Very compact and well insulated 3-element galvanometer.
7. Element resistances and control to cover the broadest range of commercial testing.
8. Film, holder using standard roll film requiring no dark room.
9. Weight of complete outfit, 100 pounds.

STANDARDS FOR ELECTRIC SERVICE

Attention is called to the new edition of Circular No. 56 of the Bureau of Standards which will be published in the near future. This circular, when first issued in 1916, was very cordially received by the electric light and power industry, including both commercial and municipal plants.

The circular contains a full discussion of the engineering and technical features underlying standards for light and power service. Twenty-two states through their public service commission have adopted electric service rules, many of these being based upon suggestions contained in Circular No. 56. The new edition will present a suggested set of rules suitable for adoption in any state with such changes as may be necessary because of local conditions. Three ordinances are suggested for the regulation of the electric service by city authorities. The new circular also contains a complete digest of all state and municipal regulations now in force in the United States covering electric service.

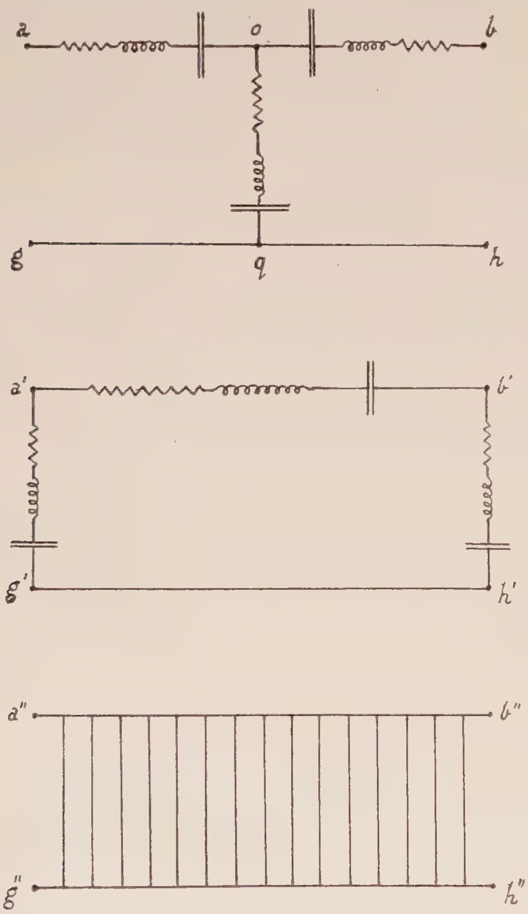
Dissymmetrical Electrical Conducting Networks

BY A. E. KENNELLY

Fellow, A. I. E. E.,

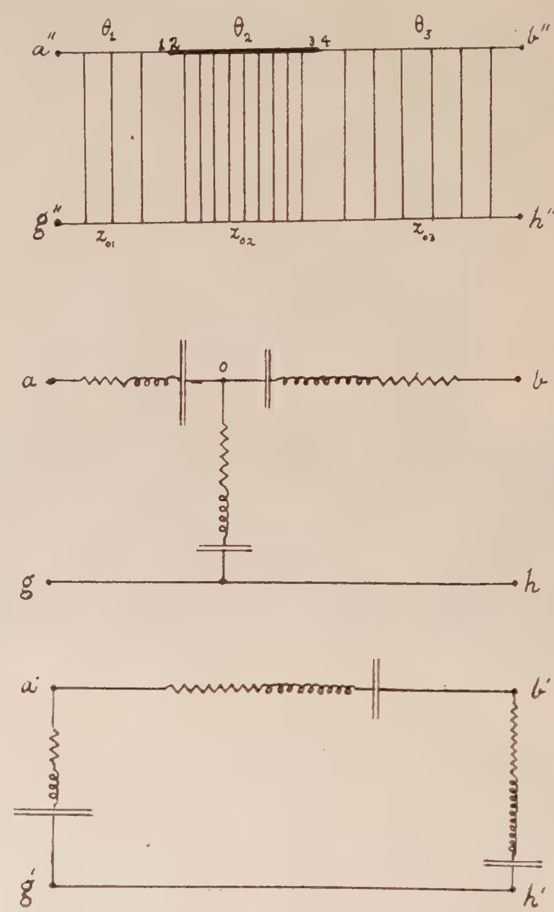
Professor of Electrical Engineering, Harvard University and Mass. Inst. Technology

IT is well known that a symmetrical T-connection of three simple impedances $a\,o$, $o\,b$, and $o\,q$, Fig. 1, in which the two arms $a\,o$, and $b\,o$ are electrically equal, and with their common terminal o connected to the ground or return conductor $g\,h$ through the impedance $o\,q$, can be completely replaced,* at any single assigned alternating-current frequency, by a certain symmetrical π, $a'\,b'\,g'\,h'$, Fig. 2, in which the two pillars $a'\,g'$ and $b'\,h'$, have equal impedances; also that either of these two symmetrical systems can be completely replaced, at the same frequency,† by a single smooth line conductor $a''\,b''$, Fig. 3, having uniformly distributed series impedance in its conductor and also uniformly distributed lateral leak admittance between the conductor and the return conductor $g''\,h''$. Such a line conductor may be regarded as subtending or



FIGS. 1, 2 AND 3—SYMMETRICAL T, π AND SMOOTH LINE, EQUIVALENT AND INTERCHANGEABLE

possessing, at the frequency in question, a certain complex hyperbolic angle θ, and also a certain single surge impedance or "characteristic impedance," z_0 ohms. Consequently, both the symmetrical T conducting system of Fig. 1, and the symmetrical π of Fig. 2, may be regarded as possessing the same complex angle θ and surge impedance z_0, by virtue of equivalence. In any network of conductors, carrying alternating currents of the assigned frequency in the steady state, any of the three equivalent systems of Figs. 1,



FIGS. 4, 5 and 6—COMPOSITE LINE OF THREE SECTIONS WITH ITS EQUIVALENT DISSYMMETRICAL T AND π

2 and 3 may be interchanged, without disturbing the distributions of potential, current and power, at and outside the terminals of the system.

Moreover, if two or more simple smooth line conductors, of the type indicated in Fig. 3, are connected in series to form a composite line as in Fig. 4, it is known that the composite line system $a''\,b''\,g''\,h''$ (Fig. 4) can be replaced by its equivalent T of Fig. 5,‡ or by its equivalent π of Fig. 6, and that these equivalent conductors are, in general, dissymmetrical. For a given composite-line system of Fig. 4 operated in the steady state at a single frequency, there can be only one equivalent T and also only one equivalent π. On the other hand, neither the equivalent T of Fig. 5, nor the equiva-

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* Bibliography (1).

† Bibliography (3).

‡ Bibliography (4).

lent π of Fig. 6 can determine the elements of smooth line section in the equivalent composite-line system of Fig. 4. In the absence of specific information concerning the number and characters of the component-line sections, an infinite number of different composite-line systems like that of Fig. 4, could be found as equivalents for the dissymmetrical T or π of Figs. 5 and 6. The question thus arises as to what is the simplest smooth-line system which can replace a given

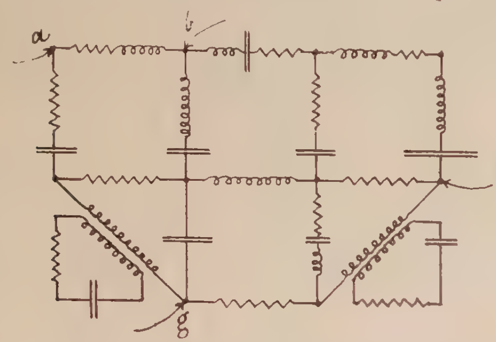


FIG. 7—NETWORK OF IMPEDANCES REPLACEABLE BY ONE DISSYMMETRICAL T OR π WITH RESPECT TO THE TWO PAIRS OF TERMINALS, a, g, AND b, h.

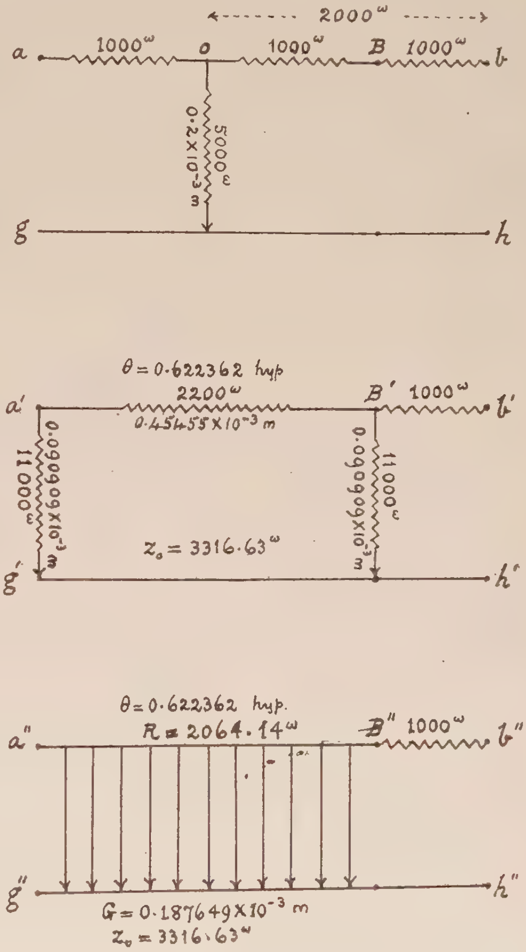
dissymmetrical T and its corresponding dissymmetrical π?

Again, if any network of conductors, such as that of Fig. 7, carrying alternating currents of a single frequency, and two pairs of terminals are selected arbitrarily from the system, such as a, g, and b, h; then the system behaves with respect to these pairs of terminals like a certain equivalent T of Fig. 5, and also like the corresponding equivalent π of Fig. 6, these two systems being mutually equivalent and, in general, dissymmetrical. The question then also arises as to what is the simplest smooth-line conductor system which can be regarded as replacing the network, with respect to the pairs of terminals a, g and b, h?

A symmetrical network of conductors, with respect to two pairs of terminals, may be defined as one whose equivalent T and π are symmetrical, like Figs. 1 and 2. A dissymmetrical network is then one which, with respect to the two pairs of terminals, has a dissymmetrical equivalent T and π, like Figs. 5 and 6. In general, networks are dissymmetrical, and symmetrical networks are particular cases.

Although we always discuss a network with reference to two pairs of terminals, such as a, g and b, h in Fig. 7; yet the number of terminals involved may be reduced, in particular cases, from four to three, by the merging of two terminals. Thus, we might select the two pairs of terminals a, g and b, g, which employ the terminal g in common.

As has already been pointed out, a network which is symmetrical with respect to two pairs of terminals becomes defined either by a certain symmetrical T and π, or by a certain hyperbolic angle θ and accompanying surge impedance z_0. We can then readily compute what changes in alternating-current potential difference, current and power will be brought about at one of the pairs of terminals by any assigned electric change steadily impressed on the other pair. When, however, the network is dissymmetrical, we shall find that it requires for its definition one additional characteristic. A convenient additional characteristic is the "inequality ratio" q; so that the network acquires three characteristics θ, z_{ab} and q, which are capable of being measured in any given case, by following a suitable technique at each pair of terminals. Having ascertained these three determining characteristics for the network, we can either draw immediately its equivalent T and π; or we can compute what change in potential difference, current and power will be produced at one pair of terminals, say a, g, by a given change established steadily at the other pair b, h.



FIGS. 8, 9 AND 10—DISSYMMETRICAL T REDUCED TO SYMMETRY BY THE RETENTION OF A PERMANENT SERIES LOAD AT THE b TERMINAL WITH THE CORRESPONDINGLY LOADED π AND SMOOTH LINE.

The computation is effected by following the same process as in the symmetrical case; but with a slight modification.

The subject can best be studied with reference to continuous-current lines and networks; *i. e.*, with reference to the frequency of zero. The results so obtained are immediately applicable to alternating-

current systems, by the substitution of complex numbers for real numbers, in the well known way.

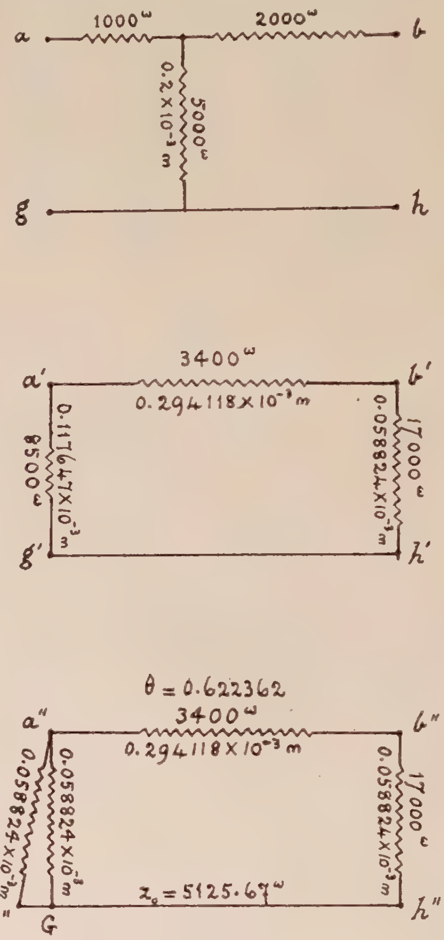
Fig. 8 shows a simple dissymmetrical T. In this particular case the branch $a\,o$ has 1000 ohms and the branch $b\,o$ 2000 ohms. Two methods suggest themselves for dealing with it; namely, (1) by reducing it to a terminally loaded symmetrical T, and (2) by retaining the dissymmetry, but making measurements from each end in turn. We may consider these two methods successively.

(1) *Method of Reduction to Symmetry.* The simplest way to reduce the T a, o, b of Fig. 8 to symmetry, is perhaps to cut off the portion B, b from the preponderating arm, so as to leave the remainder o, B equal to the branch a, o. We thus obtain symmetrical T a, o, B with a load B, b, in this case 1000 ohms, permanently attached to the terminal B. The corresponding loaded symmetrical π is shown in Fig. 9; where the same load B', b', is permanently attached to the B' terminal. Fig. 10 gives the terminally loaded smooth line a'' B'', corresponding to the combinations of Figs. 8 and 9. It has an angle of 0.622362 hyp., a surge resistance of z_0 = 3316.63 ohms, a total conductor resistance R of 2064.14 ohms and a total leakance G of 0.187649 millimho. The same load of B'' b'' = 1000 ohms is permanently attached to the B'' terminal.

It is readily possible to substitute for the dissymmetrical T a, o, b, of Fig. 8, the terminally loaded smooth line of Fig. 10, in any steady-state system. The smooth line is readily dealt with in computation, and the permanent load B'' b'' merely modifies the conditions existing at B, in a manner deducible directly from Ohm's law. If preferred, the load may be dealt with by assigning to it an auxiliary angle θ'; so that the position angle at a, becomes $\theta + \theta'$.

Although the reduction to symmetry effected by reducing the higher-impedance branch of the T to equality with the lower-impedance branch, is perhaps the simplest, especially in a continuous-current case like that of Fig. 8; yet it is by no means the only method of procedure open to use. Thus, the dissymmetrical T of Fig. 8, might be replaced by its corresponding dissymmetrical equivalent π, as in Figs. 11 and 12. The π, a' b' g' h' of Fig. 12 may be reduced to symmetry, by cutting off part of the leak a' g' as a terminal load, and leaving the remainder at a'' G, Fig. 13, equal to the leak b'' h''. This leaves the symmetrical π, a'' b'' G h'', of angle θ = 0.622362 and surge impedance z_0 = 5125.67 ohms, but with the leak a'' g'' of 0.058824 millimho permanently attached to a''. This symmetrical π might now be replaced either by a leak-loaded symmetrical T, or by a smooth line with the same terminal leak load.

Again it would be possible to reduce the T of Figs. 8 and 11 to symmetry, by employing permanent pairs of unequal terminal series loads, as for instance 100 ohms at a, and 1100 ohms at b, so as to produce a symmetrical T with 900 ohms in each branch. This could be done in an infinite number of ways, each giving a different θ, a different z_0, and a different pair of permanent terminal loads. It would also be possible to reduce the π of Fig. 12 to symmetry, by employing pairs of unequal terminal leak loads. There would be an infinite number of such possible pairs, with corresponding values of θ and z_0. Consequently, a dissymmetrical network admits of being reduced to symmetry for computation, in one way with a single ter-



FIGS. 11, 12 AND 13. DISSYMMETRICAL T REPLACED BY ITS CORRESPONDINGLY DISSYMMETRICAL π, WHICH IS REDUCED TO SYMMETRY BY THE RETENTION OF A PERMANENT LEAK AT THE a'' TERMINAL.

minal series load, in one way with a single terminal leak load, in an infinite number of ways with a pair of opposite terminal series loads, and also in an infinite number of ways with a pair of opposite terminal leak loads. In practise, the two single-load methods are preferable and easier to use.

(2) *The Method of Applying the Inequality Ratio q.* In this method, the system is left in its dissymmetrical state; but measurements are made from each pair of terminals in turn, to determine the apparent surge impedance from each end.

Returning to the dissymmetrical T of Figs. 8 and 11, we can measure the resistance R_{af} offered between the terminal a and the return conductor or ground g, when

the system is freed or opened at the opposite terminals b, h. We may also measure the resistance R_{ag} offered between the same terminals at a, when the end b is grounded, or the terminals b, h are short-circuited. Following the usual rule for finding the angle of a symmetrical smooth line, the apparent angle of the system is expressed by:

$$\tanh \theta = \sqrt{R_{ag}/R_{af}} \qquad \text{numeric } \angle \qquad (1)$$

In the particular case of Fig. 8, the resistance R_{ag} would be 2428.57 ohms, and $R_{af} = 6000$ ohms, from which $\tanh \theta = 0.636209$ and $\theta = 0.751779$ hyp. ra-

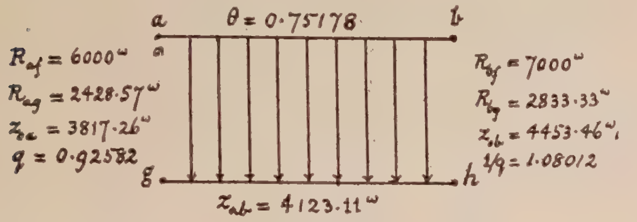


Fig. 14—Network of Fig. 11 with Single Angle θ, but with Surge Impedances z_{0a} and z_{0b} as Determined From Each End.

dians. Similarly, according to the regular rule for a symmetrical line, the apparent surge impedance z_{0a} from the end a, is

$$z_{0a} = \sqrt{R_{af} \cdot R_{ag}} \qquad \text{ohms } \angle \qquad (2)$$

which in the case considered, is 3817.26 ohms. If now we repeat the measurements from the b end, successively freeing and grounding the a terminal, we find R_{bf} and R_{bg}, which would be 7000 and 2833.33 ohms respectively. As before,

$$\tanh \theta = \sqrt{R_{bg}/R_{bf}} = 0.636209 \qquad \text{numeric } \angle \qquad (3)$$

whence $\theta = 0.751779$. This is the same value as was found by (1), from the measurements at a. We may express this relation as a general rule thus: If in any dissymmetrical network of conductors, such as that of Fig. 7, we take two pairs of terminals like a, g, and b, h, and measure, at an assigned frequency, the impedance offered by the network between each pair, with the opposite pair first opened and then shorted, we may denote these impedances by R_{af}, R_{ag} and R_{bf}, R_{bg}, ohms $\angle$ respectively. Then the ratios R_{ag}/R_{af} and R_{bg}/R_{bf} will be equal to each other, and to the square of the tangent of the angle subtended by the network with respect to those four terminals.

On the other hand, if the network is dissymmetrical, the apparent surge impedance from b, or

$$z_{0b} = \sqrt{R_{bf} \cdot R_{bg}} \qquad \text{ohms } \angle \qquad (4)$$

will not be the same as z_{0a}. In the case considered, $z_{0b} = 4453.46$ ohms. The geometrical mean z_{ab} of the two opposite apparent surge impedances is defined by

$$z_{ab} = \sqrt{z_{0a} \cdot z_{0b}} \qquad \text{ohms } \angle \qquad (5)$$

is a characteristic property of the network, in this case 4123.11 ohms. It may be called the "geomean surge impedance" of the network.

The ratio of the a-end surge impedance z_{0a} to the geomean surge impedance z_{ab} may be called q, the "inequality ratio" of the system. It will be defined by:

$$q = z_{0a}/z_{ab} = \sqrt{R_{ag}/R_{bg}} = \sqrt{R_{af}/R_{bf}} = \sqrt{z_{0a}/z_{0b}}$$

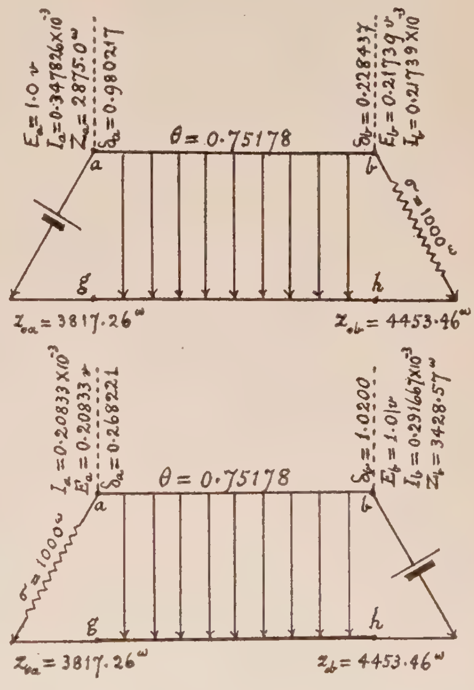
$$= \sqrt{\frac{\rho_1 + \mathfrak{R}}{\rho_2 + \mathfrak{R}}} = \sqrt{\frac{g_2 + \nu}{g_1 + \nu}} \qquad \text{numeric } \angle \qquad (6)$$

In this case the inequality ratio is $q = 0.92582$.

We may thus represent either the dissymmetrical T of Fig. 11, or its corresponding π of Fig. 12, by the dissymmetrical line system of Fig. 14. Here the line a, b, is to be regarded as a composite line, offering the same angle from each end, but different surge impedances.

Terminal Potentials and Currents in a Dissymmetrical System. If we have any physically consistent distributions of potential, current and power at the a and b terminals of a known dissymmetrical system, and we know the values of potential and current at one end, we can readily ascertain the corresponding values at the other, for one and the same frequency.

In the case of Fig. 15, we have the same dissymmetrical system as in Figs. 11, 12 and 14, for which θ, z_{0a} and z_{0b} are given. A potential of 1.0 volt and an entering current of $I_a = 0.347826$ milliampere, are found at the generating end a. Required the cor-



Figs. 15 and 16—Network Loaded with a Terminal Impedance σ at Each End Alternately

responding values at the motor end b. The value of the load σ at b need not be known. We have then:

$$E_b = \frac{1}{q}\left(E_a \cosh \theta - I_a\, z_{0a} \sinh \theta\right) \text{ volts } \angle \qquad (7)$$

and $\quad I_b = q\left(I_a \cosh \theta - E_a\, y_{0a} \sinh \theta\right)$ amperes $\angle$ (8)

where $y_{0a} = 1/z_{0a}$, is the surge admittance, as measured from a. If $q = 1$; so that the dissymmetry is made to disappear, the above formulas are those which apply

to any ordinary smooth line of θ and z_0. In the case considered, $E_b = 0.21739$ volt, and $I_b = 0.21739$ milliampere.

If on the contrary, we know E_b and I_b only, without necessarily knowing the physical conditions at the motor terminal b, we may proceed to find the corresponding values at the generator end a. We obtain:

$$E_a = q\,(E_b \cosh \theta + I_b\, z_{0b} \sinh \theta) \qquad \text{volts} \angle \quad (9)$$

and

$$I_a = \frac{1}{q}\,(I_b \cosh \theta + E_b\, y_{0b} \sinh \theta) \qquad \text{amperes} \angle \quad (10)$$

where $y_{0b} = 1/z_{0b}$ is the surge admittance as measured at b. If we make $q = 1$, these formulas become identical with those pertaining to a simple smooth line and symmetrical system. In any such smooth-line case, formulas like (7), (8), (9) and (10) can be employed for any point along the line; but in the case of a dissymmetrical system, they apply only to the terminals a and b.

Again, if b is the generator end, and a the motor end of the dissymmetrical system, (see Fig. 16), and we know the potential E_a and current I_a, at a, we can find the corresponding values at b as follows:

$$E_b = \frac{1}{q}\,(E_a \cosh \theta + I_a\, z_{0a} \sinh \theta) \qquad \text{volts} \angle \quad (11)$$

$$I_b = q\,(I_a \cosh \theta + E_a\, y_{0a} \sinh \theta) \qquad \text{amperes} \angle \quad (12)$$

Similarly, if we know the generator-end values, E_b and I_b, the corresponding motor-end values E_a and I_a become:

$$E_a = q\,(E_b \cosh \theta - I_b\, z_{0b} \sinh \theta) \qquad \text{volts} \angle \quad (13)$$

$$I_a = \frac{1}{q}\,(I_b \cosh \theta - E_b\, y_{0b} \sinh \theta) \qquad \text{amperes} \angle \quad (14)$$

Here again, if $q = 1$, the formulas are those which apply at the terminals of a smooth line and symmetrical system. Hence we may formulate the following rule for any dissymmetrical case. Having given the potential and current at one end, write the corresponding values for the other, with regard to the direction of power transmission, as though the line were smooth and the system symmetrical. Use the surge impedance or admittance belonging to the end at which the values are known. Then an unknown potential E_a at a, will be $q = \sqrt{z_{0a}/z_{0b}}$ times that found by the regular formula, and likewise an unknown current I_b at b. On the other hand, an unknown current I_a at a, or a potential E_b at b, will be $1/q$ times that found by the regular smooth-line formula. The power products $E_a\, I_a$, and $E_b\, I_b$ will therefore not differ from those given by the corresponding smooth-line formulas.

Position Angles at the Terminals of a Dissymmetrical System. If we load the motor end b of a dissymmetrical system, like that of Fig. 15, with an impedance σ ohms $\angle$, we may find the position angle of that end in the same manner as though the load were applied to the motor end of a simple smooth line; *i. e.*

$$\tanh \delta_b = \sigma/z_{0b} \qquad \text{numeric} \angle \quad (15)$$

Thus in Fig. 15, the position angle δ_b at b is 0.228437 hyp. The position angle δ_a at the generator end a is then obtained by the usual rule:

$$\delta_a = \theta + \delta_b \qquad \text{hyps} \angle \quad (16)$$

which in this case is 0.980217 hyp. The potentials and currents at the ends of the dissymmetrical system are then related as follow:

With E_b and I_b known,

$$E_a = q\left(E_b\,\frac{\sinh \delta_a}{\sinh \delta_b}\right) \qquad \text{volts} \angle \quad (17)$$

$$I_a = \frac{1}{q}\left(I_b\,\frac{\cosh \delta_a}{\cosh \delta_b}\right) \qquad \text{amperes} \angle \quad (18)$$

The impedance beyond b is σ. The impedance at a is:

$$Z_a = z_{0a} \tanh \delta_a \qquad \text{ohms} \angle \quad (19)$$

The power at a is the local product of E_a and I_a in vector watts, according to the regular rule.

With E_a and I_a known,

$$E_b = \frac{1}{q}\left(E_a\,\frac{\sinh \delta_b}{\sinh \delta_a}\right) \qquad \text{volts} \angle \quad (20)$$

$$I_b = q\left(I_a\,\frac{\cosh \delta_b}{\cosh \delta_a}\right) \qquad \text{amperes} \angle \quad (21)$$

Formulas (17) to (21) apply to ordinary smooth-line symmetrical systems, if $q = 1$. Whereas, however, in a smooth-line system, a position angle can be assigned to each and every point of the line, we are only justified in assigning position angles to two points—the a and b ends—of a dissymmetrical system.

Similarly, if b is the generator end (Fig. 16) and a the motor end of a dissymmetrical system, to which a load σ is applied, the position angle at a is defined by:

$$\tanh \delta_a = \sigma/z_{0a} \qquad \text{numeric} \angle \quad (22)$$

In the case considered, $\delta_a = 0.268221$ hyp. The position angle at b is:

$$\delta_b = \theta + \delta_a \qquad \text{hyps} \angle \quad (23)$$

The potentials and currents at the two ends are thus related:

With E_b and I_b known,

$$E_a = q\left(E_b\,\frac{\sinh \delta_a}{\sinh \delta_b}\right) \qquad \text{volts} \angle \quad (24)$$

$$I_a = \frac{1}{q}\left(I_b\,\frac{\cosh \delta_a}{\cosh \delta_b}\right) \qquad \text{amperes} \angle \quad (25)$$

With E_a and I_a known,

$$E_b = \frac{1}{q}\left(E_a\,\frac{\sinh \delta_b}{\sinh \delta_a}\right) \qquad \text{volts} \angle \quad (26)$$

$$I_b = q\left(I_a\,\frac{\cosh \delta_b}{\cosh \delta_a}\right) \qquad \text{amperes} \angle \quad (27)$$

The impedance at the generator end is:

$$Z_b = z_{0b} \tanh \delta_b \qquad \text{ohms} \angle \quad (28)$$

Formulas (24) to (27) are identical with (17), (18) and (20), (21).

We may formulate the deductions from the last 13 formulas as follow: In any dissymmetrical system for which θ, z_{0a} and z_{0b} are given, and which is loaded at the

motor end with an impedance σ, find the position angle at the motor end, with reference to that end's surge impedance. If the potential and current are given at one end of the system, the values at the other end are found by using the ordinary position-angle formulas for a smooth line. An unknown E_a, or I_b, will then be $q = \sqrt{z_{0a}/z_{0b}}$ times the value so obtained. On the other hand, an unknown E_b or I_a, will be $1/q$ times the value obtained by the ordinary formula. This rule agrees with that given above for use with formulas (**7**) to (**14**).

In view of the above mentioned reciprocal factors for potential and current at each terminal, leaving the power products unchanged, it becomes possible to reduce a dissymmetrical system to a corresponding symmetrical system plus a terminal ideal transformer, without losses, and with a transformation ratio of q. It is doubtful, however, there would be any advantage in this plan over the method above outlined.

In the case of an actual composite line, like that of Fig. 4, with definite sections, having respective angles θ_1, θ_2, θ_3 . . . and surge impedances z_{01}, z_{02}, z_{03}, . . ., it is advantageous to work up the position angles at the successive terminals commencing with the motor end. The terminal position angle at a would thus become δ_1, with a terminal surge impedance z_{01}; while working from the other end, the terminal position angle would be δ_n, with a terminal surge impedance of z_{0n}. The impedance R_{ag} as measured at a would be

$$R_{ag} = z_{01} \tanh \delta_1 \qquad \text{ohms } \angle \qquad (\mathbf{29})$$

while that measured at b would be

$$R_{bg} = z_{0n} \tanh \delta_n \qquad \text{ohms } \angle \qquad (\mathbf{30})$$

These values are not inconsistent with (**19**) and (**28**), which pertain to a general network; whereas (**29**) and (**30**) pertain to a particular composite line with detailed sections.

Receiving-End Impedance of a Dissymmetrical Network. If we define this quantity as the ratio of the e. m. f. impressed at the generator terminals to the current received through a load connecting the motor terminals, we find that for a load σ at b, (Fig. 15), the receiving end impedance is:

$$Z_{lb} = q\,(z_{0b} \sinh \theta + \sigma \cosh \theta) \qquad \text{ohms } \angle \qquad (\mathbf{31})$$

In the case represented in Fig. 15, Z_{lb} = 4600.0 ohms. When $q = 1$, this expression reduces to the ordinary value $z_0 \sinh \theta + \sigma \cosh \theta$, for a simple smooth line or symmetrical system.

When $\sigma = 0$, or the b terminals are short-circuited, (**31**) becomes:

$$Z_{lb} = q\, z_{0b} \sinh \theta = z_{ab} \sinh \theta \qquad \text{ohms } \angle \qquad (\mathbf{32})$$

which is the architrave impedance in Fig. 12, or 3400.0 ohms.

Similarly, for a load of σ ohms $\angle$ at the motor end a, the receiving-end impedance becomes (Fig. 16.)

$$Z_{la} = \frac{1}{q}\,(z_{0a} \sinh \theta + \sigma \cosh \theta) \qquad \text{ohms } \angle \qquad (\mathbf{33})$$

In the case of Fig. 16, this becomes 4800.0 ohms. When $q = 1$, the expression (**33**) again coincides with the ordinary smooth-line formula. Moreover, when $\sigma = 0$,

$$Z_{la} = \frac{1}{q}\,(z_{0a} \sinh \theta) = z_{ab} \sinh \theta \qquad \text{ohms } \angle \qquad (\mathbf{34})$$

or 3400.0 ohms, the architrave impedance of the equivalent dissymmetrical π.

We may formulate these results as follows. The receiving-end impedance of a dissymmetrical network loaded at the receiving end, is found by the usual rule

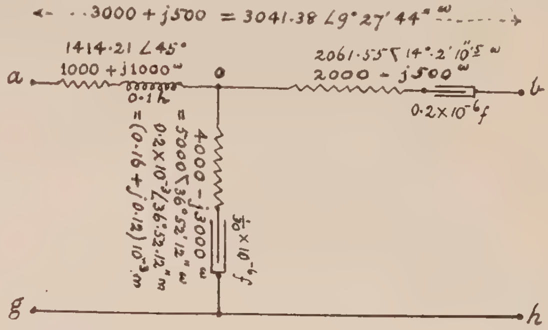


FIG. 17—DISSYMMETRICAL T OF IMPEDANCE REPRESENTING A NETWORK OF ALTERNATING-CURRENT CONDUCTORS

for a terminally loaded smooth line, using the surge impedance of the motor end. The result must then be multiplied by q, when the generator is at a, and by $1/q$ when the generator is at b. In case the load is short-circuited, the receiving-end impedance reduces to $\rho'' = z_{ab} \sinh \theta$, the architrave impedance of the equivalent dissymmetrical π.

Technique of Measurements. We have assumed that the measurements made on the network are the four terminal impedances R_{af}, R_{ag}, R_{bf}, and R_{bg}. In cases where there is but little difference between R_{af} and R_{ag},

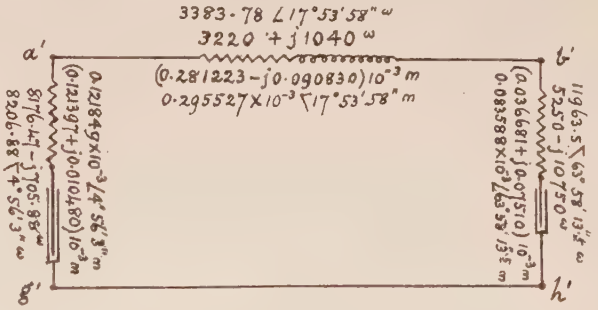


FIG. 18—DISSYMMETRICAL EQUIVALENT π OF SAME

or between R_{bf} and R_{bg}, the value of θ may not admit of being determined with satisfactory precision; although the value of z_{ab} will usually be acceptable. In such a case, if the two ends of the network can be brought to the same testing table, it may be preferable to adopt the following technique:

1. Measure, with b open, the impedance R_{af} ohms at a, and the entering current I_a at a. At the same time measure the vector p. d. e_b volts thereby produced at the b terminals. From these data, ρ_1 and $\mathfrak{R}$ can be deduced.

2. Measure R_{ag} ohms $\angle$ at a. With this value and R_{af}, find z_{0a}, by (**2**).

3. Repeat the measurements (**1**) and (**2**) reciprocally with the ends of the network reversed, so as to obtain R_{bf}, e_a and R_{bg}. These will give ρ_2 and z_{0b}, together with check values of θ and $\mathfrak{R}$.

Example of a Dissymmetrical Alternating-Current System. Fig. 17 offers a particular dissymmetrical

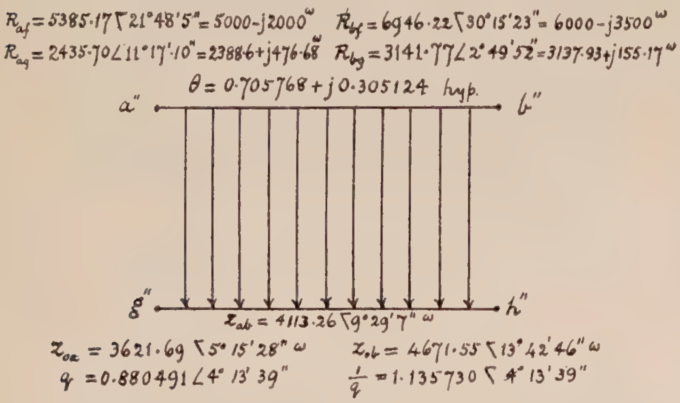


Fig. 19—Network of Fig. 17 with Single Angle θ, but with Surge Impedances z_{0a} and z_{0b} as Determined from Each End.

T system, which might be the equivalent of a certain network between the two pairs of terminals a, g and b, h. The impedance $a\,o$, is $1000 + j\,1000$ ohms, such as might be produced by an inductor of 0.1 henry and 1000 ohms, at an angular velocity of $\omega = 10000$ radians per second, (1591.5 ~). The impedance $o\,b$ is $2000 - j\,500$ ohms, such as might be produced at the same frequency by a condenser of 0.2 microfarad, in series with 2000 ohms. The impedance

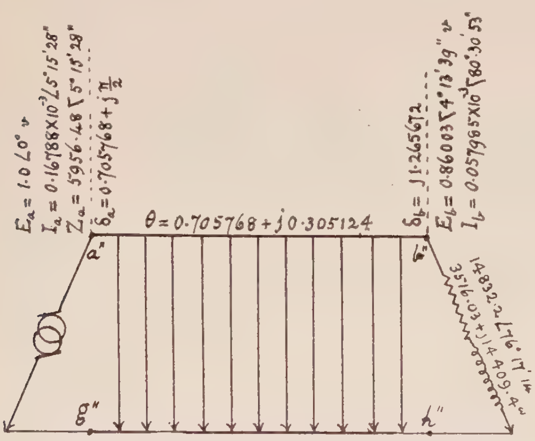


Fig. 20—Same with Terminal Load at b

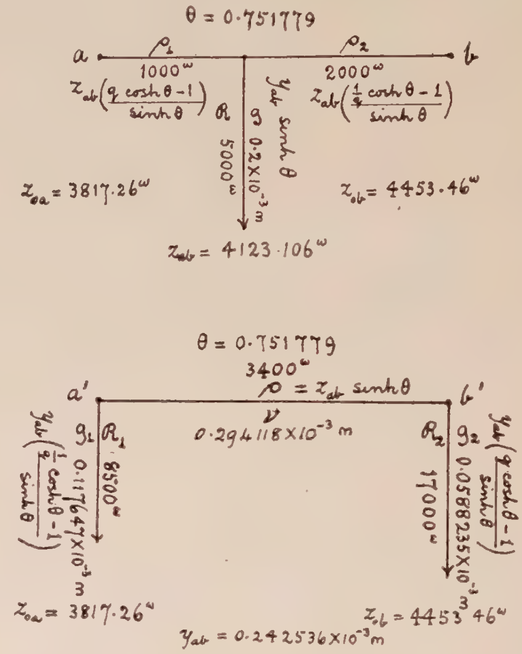
$o\,g$ is $4000 - j\,3000$ ohms. The equivalent π of this system is given in Fig. 18, and the equivalent composite line network in Fig. 19. The angle subtended by the network is $\theta = 0.705768 + j\,0.305124$ hyps; or quadranting the imaginary part $\theta = 0.705768 + j\,0.\overline{194248}$ hyps. The functions of this angle are:

$$\sinh\theta = 0.822652 \angle 27°\,23'\,05''$$
$$\cosh\theta = 1.223218 \angle 10°\,50'\,28''$$
$$\tanh\theta = 0.672531 \angle 16°\,32'\,37''$$

Many of the formulas in Appendix A can be checked from Figs. (17), (18) and (19) by an inspection of the slopes of the various complex quantities presented.

In Fig. 20, the system of Figs. (17), (18) and (19) is represented as being loaded at the b end with $\sigma = 3516.03 + j\,14409.4$ ohms, and supplied at the a end with an e. m. f. of $1.0 \angle 0°$ volt at the frequency of reference. The terminal position angles, potentials and currents are marked on the Figure, in accordance with formulas (**15**) to (**21**).

In Appendix A, a number of formulas have been collected relating to dissymmetrical networks and their equivalent circuits. The notation is in accordance with Figs. 21 and 22, and the numerical values pertain to the particular case of Figs. 14, 15 and 16.



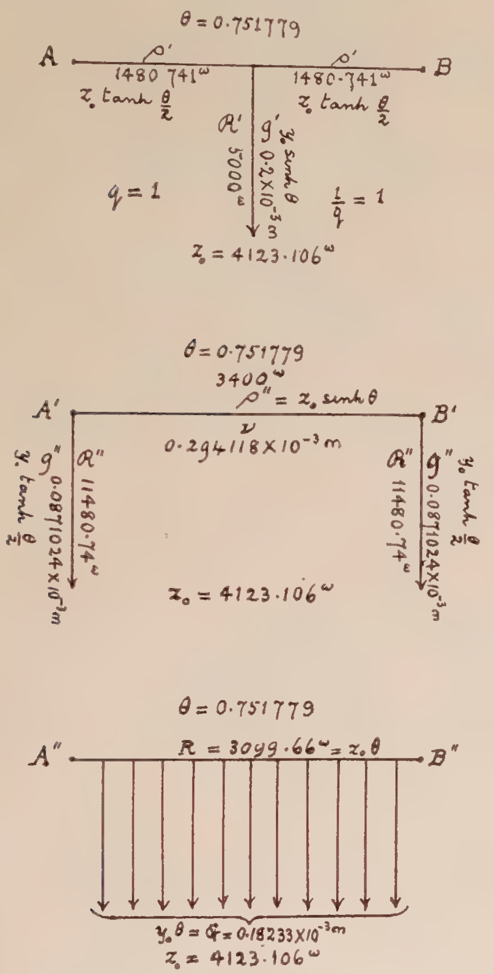
Figs. 21 and 22—Dissymmetrical T and π with Their Elements Symbolized, Also Numerical Values Conforming with the Particular Case of Figs. 11, 12 and 14.

In Appendix B, a corresponding series of formulas has been collected, relating to symmetrical networks and their equivalent circuits; *i. e.*, for the case $q = 1$. The notation is in accordance with Figs. 23, 24 and 25. The numerical values pertain to the system having the same θ as in Figs. 14, 15 and 16 and with its surge impedance z_0 equal to the geomean surge impedance z_{ab} of the dissymmetrical system. The values of R_f and R_g in this case are respectively the geomean values of R_{af}, R_{bf} and R_{ag}, R_{bg}.

We have considered, in all of the cases represented by the figures, that in any dissymmetrical T, all of the series impedance is lodged in the conductor a, o, b, and that the return conductor g, h, has negligible impedance. According to the known theory of T conductors, however, any desired share of series impedance can be transferred from a, o, b, to g, h, without disturbing the e. m. fs., currents and powers at and

beyond the system terminals, provided that the total series impedance on the a side of the leak $o\,q$ is constant, and likewise the total series impedance on the b side. In other words a T-system may be converted into a H-system.

Similarly, although in all the π-systems indicated in the Figures, all the series impedance is lodged in the conductor a', b'; yet any desired share of this impedance may be transferred to g', h', without disturbing the e. m. fs., currents and powers at and beyond the system terminals. In other words, the dissymmetrical π s may be converted into corresponding O-systems.



FIGS. 23, 24 AND 25—SYMMETRICAL T, π AND SMOOTH LINE HAVING THE SAME ANGLE FEEDER AS IN FIGS. 14, 21 AND 22, ALSO WITH $z_o = z_{ab}$ OF THE DISSYMMETRICAL CASE.

SUMMARY OF CONCLUSIONS

1. Any dissymmetrical conducting network, each element of which obeys Ohm's law generalized for alternating currents, may be reduced to symmetry, with respect to two pairs of terminals, and at an assigned frequency, either by finding its equivalent T and equating the two arms, through the medium of a permanent series terminal load; or, by finding its equivalent π and equating the two pillars, through the medium of a permanent terminal leak load. The system then offers a certain angle θ, a surge impedance z_0, and a single terminal load, which may be treated as having an auxiliary angle θ'.

2. Any such dissymmetrical network may also be regarded as possessing and being defined by (a) an angle θ, (b) a geomean surge impedance z_{ab}, and (c) an inequality ratio q. The electric behavior of the network, at the assigned frequency, with respect to the two pairs of terminals, may then be computed by the usual formulas applying to a simple smooth line; but with the further application of the coefficient q.

3. The theory of simple alternating-current lines with smoothly distributed constants may thus be regarded as being a particular case ($q = 1$) of the general theory of dissymmetrical networks having any degree of complexity.

LIST OF SYMBOLS EMPLOYED

δ_a, δ_b,	position angles at a and b ends of a diss. network (hyps $\angle$).
δ_1, δ_n	position angles at ends of a detailed composite line (hyps $\angle$).
E_a, E_b	e. m. fs. applied to a and b ends of a diss. network (volts $\angle$).
e_a, e_b,	p. d. s at open a and b ends of diss. network by application of a testing e. m. f. at the opposite end (volts $\angle$).
f	frequency applied to network (cycles per second).
G	total conductance of a smooth sym. line (mhos $\angle$).
G_a, G_b,	admittance of a sym. system, when respectively freed and grounded at the other end (mhos $\angle$).
G_{af}, G_{ag},	admittance of a diss. system, at the a end, when respectively freed and grounded at the other end (mhos $\angle$).
G_{bf}, G_{bg},	admittance of a diss. system, at the b end, when respectively freed and grounded at the other end (mhos $\angle$).
g	admittance of leak in equiv. T of a diss. system (mhos $\angle$).
g_1, g_2,	admittances of leaks at a and b ends in equiv. π of a diss. system (mhos $\angle$).
g'	admittance of leak in equiv. T of a sym. system (mhos $\angle$).
g''	admittance of each leak in equiv. π of a sym. system (mhos $\angle$).
θ	angle subtended by a line or system (hyps $\angle$).
θ'	angle subtended by a terminal load (hyps $\angle$).
$\theta_1, \theta_2, \ldots \theta_n$	angles subtended by successive sections of a composite line (hyps $\angle$).
I_a, I_b,	current strengths at ends of a network (amperes $\angle$)
$j = \sqrt{-1}$	
ν	series adm. of a sym. or diss. π (mhos $\angle$).
$q = \sqrt{z_{0a}/z_{0b}}$	inequality ratio of a diss. network (numeric $\angle$).

R	total conductor resistance of a smooth line (ohms $\angle$).
R_f, R_g,	impedance at one end of a sym. system, when the other end is freed and grounded respectively (ohms $\angle$).
R_{af}, R_{ag},	impedance at the a end of a diss. system when the other end is freed and grounded respectively (ohms $\angle$).
R_{bf}, R_{bg},	impedance at the b end of a diss. system, when the other end is respectively freed and grounded (ohms $\angle$).
$\mathcal{R}$	impedance of leak in equiv. T of a diss. system (ohms $\angle$).
$\mathcal{R}_1, \mathcal{R}_2$,	impedances of a and b leaks in the equiv. π of a diss. system (ohms $\angle$).
$\mathcal{R}'$	impedance of leak in equiv. T of a sym. system (ohms $\angle$).
$\mathcal{R}''$	impedance of each leak in equiv. π of a sym. system (ohms $\angle$).
ρ	impedance of architrave in equiv. π of a diss. system (ohms $\angle$).
ρ_1, ρ_2,	impedance of a and b arms in equiv. T of a diss. system (ohms $\angle$).
ρ'	impedance of each arm in equiv. T of a sym. system (ohms $\angle$).
ρ''	impedance of architrave in equiv. π of a sym. system (ohms $\angle$).
σ	impedance of a load at motor end of a system (ohms $\angle$).
y_0	surge admittance of a sym. system (mhos $\angle$).
y_{0a}, y_{0b},	surge admittance at a and b ends of a diss. system (mhos $\angle$).
$y_{ab} = \sqrt{y_{0a} y_{0b}}$	geometrical mean surge admittance of a diss. system mhos $\angle$).
Z_a, Z_b,	generator-end impedances of a diss. system (ohms $\angle$).
Z_{la}, Z_{lb},	receiving-end impedances of a diss. system, including load (ohms $\angle$).
z_0,	surge impedance of a sym. system (ohms $\angle$).
z_{0a}, z_{0b},	surge impedance at a and b ends of a diss. system (ohms $\angle$).
$z_{ab} = \sqrt{z_{0a} z_{0b}}$	geomean surge impedance of a diss. system (ohms $\angle$).
$z_{01}, z_{02}, \ldots z_{0n}$	surge impedances of successive sections in composite line (ohms $\angle$).
$\omega = 2\pi f$	angular velocity of frequency impressed on a system (rad. per sec.)
$\sim$	sign for "cycles per second."
$\angle$	sign for a complex numerical quantity.
hyp.	abbreviation for "hyperbolic radian."

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Without pretensions as to completeness

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APPENDIX A

List of formulas applicable to a dissymmetrical T, π or Network. The numerical values pertain to the case of Figs. 17, 18, 21 and 22.

$$R_{ag}/R_{af} = R_{bg}/R_{bf} = G_{af}/G_{ag} = G_{bf}/G_{bg} = \frac{\mathcal{R}(\rho_1+\rho_2)+\rho_1\rho_2}{(\mathcal{R}+\rho_1)(\mathcal{R}+\rho_2)} = \frac{\nu(g_1+g_2)+g_1 g_2}{(\nu+g_1)(\nu+g_2)} = \tanh^2\theta = 0.404762 \quad \text{numeric } \angle \quad (35)$$

$$\rho_1/\rho_2 = g_2/g_1 = \mathcal{R}_1/\mathcal{R}_2 = \frac{q\cosh\theta - 1}{\frac{1}{q}\cosh\theta - 1} = 0.5 \quad \text{numeric } \angle \quad (36)$$

$$q = \sqrt{R_{ag}/R_{bg}} = \sqrt{R_{af}/R_{bf}} = \sqrt{G_{bg}/G_{ag}} = \sqrt{G_{bf}/G_{af}} = \sqrt{z_{0a}/z_{0b}} = \sqrt{\frac{\rho_1+\mathcal{R}}{\rho_2+\mathcal{R}}} = \sqrt{\frac{g_2+\nu}{g_1+\nu}} = z_{0a}/z_{ab} = 0.92582 \quad \text{numeric } \angle \quad (37)$$

$$1/q = \sqrt{R_{bg}/R_{ag}} = \sqrt{R_{bf}/R_{af}} = \sqrt{G_{ag}/G_{bg}} = \sqrt{G_{af}/G_{bf}} = \sqrt{z_{0b}/z_{0a}} = \sqrt{\frac{\rho_2+\mathcal{R}}{\rho_1+\mathcal{R}}} = \sqrt{\frac{g_1+\nu}{g_2+\nu}} = z_{0b}/z_{ab} = 1.08012 \quad \text{numeric } \angle \quad (38)$$

$$\frac{\frac{1}{2}(\rho_1+\rho_2)}{\mathcal{R}} = \frac{\frac{1}{2}(g_1+g_2)}{\nu} = \left(\frac{q+1/q}{2}\right)\cosh\theta - 1 = 0.3 \quad \text{numeric } \angle \quad (39)$$

$$\frac{\sqrt{\rho_1\rho_2}}{\mathcal{R}} = \frac{\sqrt{g_1 g_2}}{\nu} = \sqrt{(q\cosh\theta - 1)\left(\frac{1}{q}\cosh\theta - 1\right)} = 0.28284 \quad \text{numeric } \angle \quad (40)$$

$$\rho_1/g_2 = \rho_2/g_1 = \rho_1\,\mathcal{R}_2 = \rho_2\,\mathcal{R}_1 = \rho\,\mathcal{R} = \rho/g = \mathcal{R}/\nu = \sqrt{\frac{\rho_1\,\rho_2}{g_1\,g_2}} = z_{0a}\,z_{0b} = z_{ab}^2 = R_{af}\,R_{bg}$$
$$= R_{ag}\,R_{bf} = \rho_1\,\rho_2 + \mathcal{R}\,(\rho_1+\rho_2) = \sqrt{R_{af}\,R_{ag}\,R_{bf}\,R_{bg}} = \sqrt{\rho_1\,\rho_2\,\mathcal{R}_1\,\mathcal{R}_2}$$
$$= \sqrt{\{\rho_1(\rho_2+\mathcal{R})+\rho_2\,\mathcal{R}\}\ \{\rho_2(\rho_2+\mathcal{R})+\rho_1\,\mathcal{R}\}} = 17{,}000{,}000 = (4123.106)^2 \quad \text{ohms}^2\angle \quad (41)$$

$$g_1/\rho_2 = g_2/\rho_1 = \nu\,g = g/\rho = \nu/\mathcal{R} = \sqrt{\frac{g_1\,g_2}{\rho_1\,\rho_2}} = y_{0a}\,y_{0b} = y_{ab}^2 = G_{af}\,G_{bg} = G_{ag}\,G_{bf}$$
$$= g_1\,g_2 + \nu\,(g_1+g_2) = \sqrt{G_{af}\,G_{ag}\,G_{bf}\,G_{bg}} = \sqrt{\{g_1(g_2+\nu)+g_2\,\nu\}\ \{g_2(g_1+\nu)+g_1\,\nu\}}$$
$$= 0.058824\times10^{-6} = (0.2425355\times10^{-3})^2 \quad \text{mhos}^2\angle \quad (42)$$

$$z_{0a} = \sqrt{R_{af}\,R_{ag}} = \sqrt{\rho_1(\rho_1+\mathcal{R})+\rho_2\,\mathcal{R}\,\frac{\rho_1+\mathcal{R}}{\rho_2+\mathcal{R}}} = q\,z_{ab} = q^2\,z_{0b} = 3817.26 \quad \text{ohms}\ \angle \quad (43)$$

$$z_{0b} = \sqrt{R_{bf}\,R_{bg}} = \sqrt{\rho_2(\rho_2+\mathcal{R})+\rho_1\,\mathcal{R}\,\frac{\rho_2+\mathcal{R}}{\rho_1+\mathcal{R}}} = \frac{1}{q}\,z_{ab} = \frac{1}{q^2}\,z_{0a} = 4453.46 \quad \text{ohms}\ \angle \quad (44)$$

$$\sinh\theta = \sqrt{\frac{R_{ag}}{R_{af}-R_{ag}}} = \sqrt{\frac{R_{bg}}{R_{bf}-R_{bg}}} = \frac{\sqrt{\mathcal{R}\,(\rho_1+\rho_2)+\rho_1\,\rho_2}}{\mathcal{R}} = \frac{\sqrt{\nu\,(g_1+g_2)+g_1\,g_2}}{\nu}$$
$$= \sqrt{\rho/\mathcal{R}} = \sqrt{\rho\,g} = z_{ab}/\mathcal{R} = y_{ab}/\nu = 0.82462 \quad \text{numeric}\ \angle \quad (45)$$

$$\cosh\theta = \sqrt{\frac{R_{af}}{R_{af}-R_{ag}}} = \sqrt{\frac{R_{bf}}{R_{bf}-R_{bg}}} = \frac{\sqrt{(\mathcal{R}+\rho_1)(\mathcal{R}+\rho_2)}}{\mathcal{R}} = \sqrt{1+\rho\,g}$$
$$= \frac{\sqrt{(\nu+g_1)(\nu+g_2)}}{\nu} = \frac{\sqrt{R_{af}\,R_{bf}}}{\mathcal{R}} = \frac{\sqrt{G_{ag}\,G_{bg}}}{\nu} = 1.296148 \quad \text{numeric}\ \angle \quad (46)$$

$$\tanh\theta = \sqrt{R_{ag}/R_{af}} = \sqrt{R_{bg}/R_{bf}} = = \sqrt{\frac{\mathcal{R}\,(\rho_1+\rho_2)+\rho_1\,\rho_2}{\mathcal{R}^2+\mathcal{R}\,(\rho_1+\rho_2)+\rho_1\,\rho_2}}$$
$$= \sqrt{\frac{\nu\,(g_1+g_2)+g_1\,g_2}{\nu^2+\nu\,(g_1+g_2)+g_1\,g_2}} = \frac{z_{ab}}{\sqrt{R_{af}\,R_{bf}}} = \frac{y_{ab}}{\sqrt{G_{ag}\,G_{bg}}} = 0.636209 \quad \text{numeric}\ \angle \quad (47)$$

$$\rho_1/\mathcal{R} = \rho_1\,g = g_2/\nu = g_2\,\rho = \rho/\mathcal{R}_2 = q\cosh\theta - 1 = 0.2 \quad \text{numeric}\ \angle \quad (48)$$

$$\rho_2/\mathcal{R} = \rho_2\,g = g_1/\nu = g_1\,\rho = \rho/\mathcal{R}_1 = \frac{1}{q}\cosh\theta - 1 = 0.4 \quad \text{numeric}\ \angle \quad (49)$$

$$\rho_1 = z_{ab}\left(\frac{q\cosh\theta-1}{\sinh\theta}\right) = 1000 \quad \text{ohms}\ \angle \quad (50)$$

$$\rho_2 = z_{ab}\left(\frac{\frac{1}{q}\cosh\theta-1}{\sinh\theta}\right) = 2000 \quad \text{ohms}\ \angle \quad (51)$$

$$\mathcal{R} = z_{ab}\ \text{cosech}\ \theta = \sqrt{R_{bf}\,(R_{af}-R_{ag})} = \sqrt{R_{af}\,(R_{bf}-R_{bg})} = 5000 \quad \text{ohms}\ \angle \quad (52)$$

$$g = y_{ab}\sinh\theta = 0.2\times10^{-3} \quad \text{mhos}\ \angle \quad (53)$$

$$\rho = z_{ab}\sinh\theta = \sqrt{\frac{R_{bg}}{G_{ag}-G_{af}}} = \sqrt{\frac{R_{ag}}{G_{bg}-G_{bf}}} = R_{ag}\sqrt{\frac{R_{bf}}{R_{af}-R_{ag}}} = R_{bg}\sqrt{\frac{R_{af}}{R_{bf}-R_{bg}}}$$
$$= \frac{R_{af}\,R_{bg}}{\mathcal{R}} = \frac{R_{ag}\,R_{bf}}{\mathcal{R}} = 3400 \quad \text{ohms}\ \angle \quad (54)$$

$$\nu = y_{ab}\ \text{cosech}\ \theta = \sqrt{G_{bg}\,(G_{ag}-G_{af})} = \sqrt{G_{ag}\,(G_{bg}-G_{bf})} = \frac{G_{af}\,G_{bg}}{g} = \frac{G_{ag}\,G_{bf}}{g}$$
$$= 0.294118\times10^{-3} \quad \text{mhos}\ \angle \quad (55)$$

$$g_1 = y_{ab}\left(\frac{\frac{1}{q}\cosh\theta-1}{\sinh\theta}\right) = 0.117647\times10^{-3} \quad \text{mhos}\ \angle \quad (56)$$

$$g_2 = y_{ab}\left(\frac{q\cosh\theta - 1}{\sinh\theta}\right) = 0.058824 \times 10^{-3} \quad \text{mhos } \angle \quad (57)$$

$$R_{ag} = z_{0a}\tanh\theta = q\,z_{ab}\tanh\theta = q^2 z_{0b}\tanh\theta = 2428.57 \quad \text{ohms } \angle \quad (58)$$

$$R_{bg} = z_{0b}\tanh\theta = \frac{1}{q} z_{ab}\tanh\theta = \frac{1}{q^2} z_{0b}\tanh\theta = 2833.3 \quad \text{ohms } \angle \quad (59)$$

$$R_{af} = z_{0a}\coth\theta = q\,z_{ab}\coth\theta = q^2 z_{0b}\coth\theta = 6000 \quad \text{ohms } \angle \quad (60)$$

$$R_{bf} = z_{0b}\coth\theta = \frac{1}{q} z_{ab}\coth\theta = \frac{1}{q^2} z_{0b}\coth\theta = 7000 \quad \text{ohms } \angle \quad (61)$$

Appendix B

List of formulas applicable to a symmetrical T, π, or network, corresponding to the formulas of Appendix A. The numerical values pertain to the case of Figs. 23, 24 and 25.

$$R_g/R_f = G_f/G_g = \frac{\rho'(\rho' + 2\,\mathcal{R}')}{(\rho' + \mathcal{R}')^2} = \frac{g''(g'' + 2\,\nu)}{(g'' + \nu)^2} = \tanh^2\theta = 0.404762 \quad \text{numeric } \angle \quad (35a)$$

$$\rho'/\mathcal{R}' = g''/\nu = \rho' g' = \rho'' g'' = \cosh\theta - 1 = \text{versh}\,\theta = 2\sinh^2(\theta/2) = 0.296148 \quad \text{numeric } \angle \quad (39a)$$

$$\rho''/g' = \rho''\mathcal{R}' = \mathcal{R}'/\nu = \rho'(\rho' + 2\,\mathcal{R}') = R_f R_g = z_0^2 = (4123.106)^2 = 17{,}000{,}000 \quad \text{ohms}^2 \angle \quad (41a)$$

$$g'/\rho'' = \nu g' = \nu/\mathcal{R}' = g''(g'' + 2\,\nu) = G_f G_g = y_0^2 = (0.2425355 \times 10^{-3})^2 = 0.058824 \times 10^{-6} \quad \text{mho}^2 \angle \quad (42a)$$

$$\sinh\theta = \sqrt{\frac{R_g}{R_f - R_g}} = \frac{\sqrt{\rho'(\rho' + 2\,\mathcal{R}')}}{\mathcal{R}'} = \frac{\sqrt{g''(g'' + 2\,\nu)}}{\nu} = z_0/\mathcal{R}' = y_0/\nu = \sqrt{g'\rho''} = \sqrt{\rho''/\mathcal{R}'} = 0.82462 \quad \text{numeric } \angle \quad (45a)$$

$$\cosh\theta = \sqrt{\frac{R_f}{R_f - R_g}} = \frac{\rho' + \mathcal{R}'}{\mathcal{R}'} = \frac{g'' + \nu}{\nu} = R_f/\mathcal{R}' = G_g/\nu = \sqrt{1 + g'\rho''} = 1.296148 \quad \text{numeric } \angle \quad (46a)$$

$$\tanh\theta = \sqrt{R_g/R_f} = \frac{\sqrt{\rho'(\rho' + 2\,\mathcal{R}')}}{\rho' + \mathcal{R}'} = \frac{\sqrt{g''(g'' + 2\,\nu)}}{g'' + \nu} = z_0/R_f = y_0/G_g = 0.636209 \quad \text{numeric } \angle \quad (47a)$$

$$\rho' = z_0\left(\frac{\cosh\theta - 1}{\sinh\theta}\right) = z_0\tanh(\theta/2) = 1480.741 \quad \text{ohms } \angle \quad (50a)$$

$$\mathcal{R}' = z_0\,\text{cosech}\,\theta = R_f\,\text{sech}\,\theta = \sqrt{R_f(R_f - R_g)} = \frac{(\mathcal{R}'')^2}{\rho'' + 2\,\mathcal{R}''} = z_0^2/\rho'' = \frac{R_f R_g}{\rho''} = 5000 \quad \text{ohms } \angle \quad (52a)$$

$$g' = y_0\sinh\theta = G_f\cosh\theta = \sqrt{\frac{G_f}{R_f - R_g}} = \frac{g''(g'' + 2\,\nu)}{\nu} = y_0^2/\nu = \frac{G_f G_g}{\nu} = 0.2 \times 10^{-3} \quad \text{mhos } \angle \quad (53a)$$

$$\rho'' = z_0\sinh\theta = R_g\cosh\theta = R_g\sqrt{\frac{R_f}{R_f - R_g}} = \frac{\rho'(\rho' + 2\,\mathcal{R}')}{\mathcal{R}'} = z_0^2/\mathcal{R}' = 3400 \quad \text{ohms } \angle \quad (54a)$$

$$\nu = y_0\,\text{cosech}\,\theta = G_g\,\text{sech}\,\theta = \sqrt{G_g(G_g - G_f)} = \frac{g''(g'' + 2\,\nu)}{g'} = y_0^2/g' = \frac{G_f G_g}{g'} = 0.294118 \times 10^{-3} \quad \text{mhos } \angle \quad (55a)$$

$$g'' = y_0\left(\frac{\cosh\theta - 1}{\sinh\theta}\right) = y_0\tanh(\theta/2) = 0.0871024 \times 10^{-3} \quad \text{ohms } \angle \quad (56a)$$

$$R_g = z_0\tanh\theta = \frac{\rho'(\rho' + 2\,\mathcal{R}')}{\rho' + \mathcal{R}'} = 2623.157 \quad \text{ohms } \angle \quad (58a)$$

$$R_f = z_0\coth\theta = \rho' + \mathcal{R}' = 6480.741 \quad \text{ohms } \angle \quad (60a)$$

$$G_g = y_0\coth\theta = g'' + \nu = 0.38122 \times 10^{-3} \quad \text{mhos } \angle \quad (62)$$

$$G_f = y_0\tanh\theta = \frac{g''(g'' + 2\,\nu)}{g'' + \nu} = 0.154149 \times 10^{-3} \quad \text{mhos } \angle \quad (63)$$

Volt-Ampere Meters*

BY R. C. FRYER,

Assoc. A. I. E. E.
Superintendent Electric Meters, Union Gas & Electric Co., Cincinnati, Ohio

THE point is well known and generally accepted that many things can be done which do not become general practise until the economics governing the practise show that the difference between "cost of doing" and "earnings through doing" is on the proper side of the balance sheet.

The engineer, being a technician, may be a little slow to admit, even to himself, this fundamental; yet engineering development, in terms of actual progress for the good of all concerned, is as fully subject to the immutable law based on this fundamental as is human progress in general subject to other economic and psychological laws.

We in the engineering profession perhaps now, more than ever before, are less ready to admit that any task is impossible, yet we will have to admit that in general our research and development follow the cause of the necessity rather than precede it. This in some respects is as it should be, yet the question arises "Would not this necessity be more often clearly recognized and the solution more promptly offered if it were known that means were at hand for meeting the situation or condition brought about by that necessity?"

The first recognition of the necessity of metering or measuring kilovolt-amperes of alternating currents came through experience to manufacturers of electrical machinery. Many who do not consider themselves as aged can remember when it was common to purchase generators, motors, transformers etc. rated in kilowatts. Due either to the fact that the above machines were often required to carry inductive loads or to the fact that under these conditions controversies regarding the capacity ratings of electrical apparatus often arose the manufacturers took a wise step and changed their a-c. apparatus rating from a kilowatt to a kilovolt-ampere basis.

At the time this took place the central station industry was carrying a load in which highly inductive apparatus was the exception rather than the rule, and to a large number of central station engineers the full significance of the change was not at once apparent.

During the few years following, which really constituted the "youth" of the central station industry, the effort of the central station was to secure more load, and in the majority of cases very little thought was given to the character of the load with the exception perhaps, of its load factor. Following these years, however, some of the more progressive central stations carrying industrial loads realized that they were purchasing electrical equipment rated upon a kv-a. basis and apportioning the use of same upon a kw. basis. It became apparent that increased investment was necessary to carry an inductive load over the investment necessary to carry an equivalent non-inductive load. This not having yet become a matter of much importance to many central stations it did not attract general interest and the result was that where steps were taken to remedy conditions, such action was local in application and generally took the form of penalization of the customer operating an inductive load. Being largely local the methods and degree of penalization were varied and largely arbitrary. Perhaps we can not be sure, but it seems that, while these attempts were a step in the right direction, the "penalization idea" was not very constructive. Perhaps these attempts secured a better income on the demand charge of customers operating inductive loads, yet no basic attempt was made by manufacturers in general or by central stations to remove the infection, the result being that with each additional industrial load the condition became worse.

About the beginning of the World War many central stations generated a peak load approaching their kv-a. capacity. Finding it difficult to carry their kilowatt load without exceeding their kv-a. capacity these stations were faced with the necessity of not being able to care for all load offered or of having to enlarge generating and distributing capacity at a time when the capacity was badly needed and yet at a time when capital for same was very difficult to obtain.

This condition stimulated study of the "low power factor" or inductive load question and it was generally admitted that some action was necessary.

Study of the situation brought out the fact that about 75 to 80 per cent of the central station investment lay in the generating and distributing apparatus. It was pointed out that the carrying capacity of the apparatus covered by this portion of the investment was directly limited by the kilovolt-ampere load. From this it became apparent that while no unit of measurement defined central station capacity in terms of 100 per cent investment the unit of capacity applying directly to the greater percentage of the investment was and is the kilovolt-ampere.

Many utilities had given a power factor clause trial in their rates, but finding that this complicated their contracts; finding that many customers could not or did not understand its application; finding that most customers did not see the justice of that which they termed "penalization for low power factor;" finding they were unable to directly meter the factors involved and that the human element largely entered into calculation methods and finding that the return given a customer under "power factor correction clauses" was

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not a direct ratio to his investment in necessary correction apparatus, many utilities allowed the "power factor clause" to become a "dead letter" in the contract.

Results of the attempts cited above are given space in the *T*-2-'22 report of the Subcommittee on Power Factor and kv-a. of the National Electric Light Association Meter Committee, which states that of 418 utilities in cities of 20,000 and over in the United States and Canada, 59 show clauses relating to charges in billing low power factored customers. Among these 59 companies there are more than 20 different clauses.

During the last two years this condition of affairs has added interest to the development of

(1) Induction motors to operate at better power factors.

(2) Corrective apparatus (static and synchronous condensers).

(3) Kilovolt-ampere meters.

This has led to more study in proportioning the size of the motor to the load carried, and in obtaining both induction and synchronous motors of the proper voltage rating.

Even isolated stations generating and using their own power have found it economical to employ synchronous apparatus.

The writer recently witnessed a 20,000-kw. load in a large rubber mill near Akron, Ohio, operating at 98 per cent power factor. This was secured largely through the unusual practise of using synchronous motors specially designed for operation on rubber mill drive.

It is of course understood that at unity power factor the ordinary induction watt or watt-hour meter will measure volt-amperes or volt-ampere-hours.

It follows that if both the current and voltage fluxes in the meter be held at their proper value and in proper phase relation the meter will measure volt-ampere hours for any power factor, leading or lagging.

Your attention is also called to the fact that if the in-phase and reactive components of a circuit are properly metered the volt-amperes may be known through calculation.

In general, then, any volt ampere meter or volt ampere hour meter must, of necessity, obtain its operation from one or both the above principles.

I desire therefore, to more tersely cover the present state of volt-ampere metering art to divide the types and makes of meters as follows:

(1) Proper phase relation type meters.	Full Range	The Bodi Meter (Westinghouse)
		The Angus Meter (Esterline-Angus)
	Fixed Range	General Electric Meter
		The Lincoln Meter
(2) Resultant type meters	Full Range Indicating	The Lincoln Meter
		The Sangamo Meter
	Full Range Integrating	The Sperti-Blecksmith Meter (Westinghouse)

In the above outline only meters involving the *principle* and not the practise are mentioned. Other meters involving the above principles may now be made or may be made in the future.

The Bodi (Westinghouse) meter involves the principle of operation of the polyphase power-factor meter. It has been found that moving coils carrying the current of the circuit measured (or a portion of same) or carrying the potential of the circuit when suspended in the potential field (in one case), or in the field of the current (in the second case) will take such positions that current taken from them may be in phase with the field in which they are placed.

If then such an arrangement of coils is provided the current from it may be led through the current element of a watt or watt-hour meter and if this current is of the proper value the watt or watt-hour meter is caused to register volt amperes or volt-ampere hours. To supply such a current to the potential element of the meter involves some difficulty since the torque tending

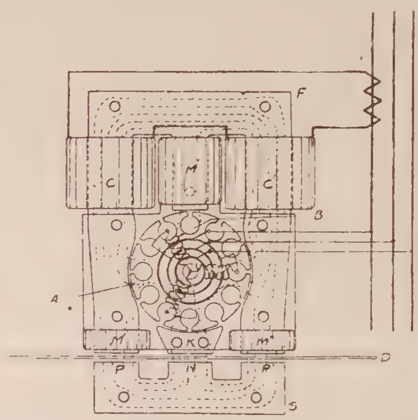

Fig. 1—One Element of the Angus 3-Phase Meter

to change the position of the movable coils with a slight change in power factor is rather small. More torque for such an arrangement may be had by connecting these movable coils in series and thus supplying current of proper phase relation to the current element of the standard watt or watt-hour meter. The difficulty encountered with this arrangement however is that the volt-ampere load of such an arrangement is rather above the secondary volt-ampere rating of standard current transformers. It must be remembered however, that with this arrangement the standard induction watt or watt-hour meter may be used.

The Angus meter employs somewhat the same principle with a slightly different arrangement. Instead of using the standard watt or watt-hour meter a special meter comprising in the case of three-phase circuits two elements (one of which is shown in Fig. 1) are used. The frame *F* is magnetized by the current coils *C* and *C*1. The potential element *A* is so mounted that it may rotate; changing its position with variation in power factor of the circuit. The polyphase winding on potential element *A* produces a rotating field about

its periphery which reacts against and with the current flux, a portion of which cuts the disk D at the points $K N$. This reaction causes the potential element, therefore, to assume a position such that its resultant flux is in phase with the field produced by the coils $C C I$, therefore, the torque on the disk is proportional to volt amperes. With a rotating disk and a register the meter becomes a volt-ampere-hour meter, since the usual type of full-load adjustment can be supplied.

Fig. 2—Angus Meter

Fig. 2 is an assembled view of the Angus meter.

As has been stated a standard watt or watt-hour meter may be caused to register volt-amperes or volt-ampere hours if potential of a degree of displacement corresponding to the displacement of the flux due to the current through the meter is supplied. If the degree of displacement of the flux in the current elements of the meter is known the potential elements of the meter may be wound to cause in their magnetic circuit the

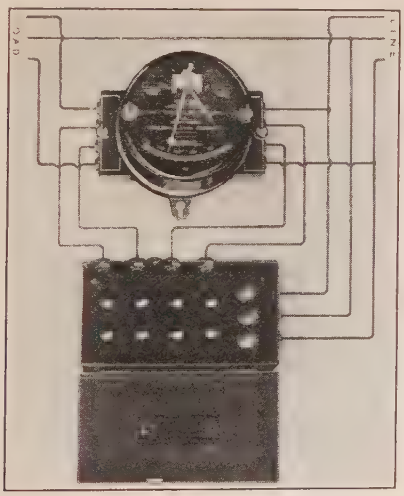

Fig. 3—Kilovolt-Ampere-Hour Meter

same degree of displacement. Under such conditions the meter will measure volt-amperes or volt-ampere hours over about 22 degrees angular range with acceptably good accuracy. The General Electric kv-a. hour meter of this type is shown in Fig. 3. Since the meter is not a standard watt-hour meter its range is increased by the addition of another shaft and necessary special potential coils on the required elements.

Both shafts are connected to one register through an overrunning clutch in such a way that the shaft which is running fastest is carrying the register. Such an arrangement practically doubles the range of the single shaft meter.

To change the range of operation beyond the 22 degrees angular range for which one set of elements is built it is necessary to add another rotor and elements or change the windings of the potential elements in use.

In Fig. 4 is shown the Lincoln type $V A D$ transformer and the Lincoln thermal, volt ampere demand meter. This is a fixed range instrument, but unlike the instrument just previously described the displacement of the potential flux does not take place in the meter itself, but is secured by picking up the desired taps supplied on the small auto transformer provided for the meter. The range of the meter is thereby

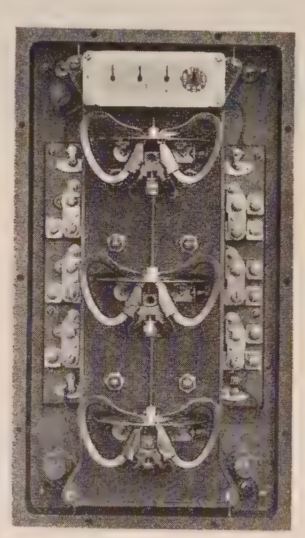

Fig. 4—3-Element Ampere Hour Meter

increased since the change necessary in widely varying power factors can be more readily made, although it must be remembered that the change is to be manually accomplished.

Mr. Paul M. Lincoln has also worked out other ideas in volt-ampere measurement which have been proved, but which are not on the market. It is understood that patents on these are held by the Westinghouse Company for the United States. In one of these meters Mr. Lincoln provides for the movement of two arms—one proportionate to kilowatts and the other proportionate to reactive volt-amperes.

These two arms are attached to a common point, the resultant movement of which is proportionate to the square root of the sum of the squares of the movements of the kw. and r. kv-a. arms, therefore, the movement of the common point is closely proportionate to volt-amperes.

In one arrangement Mr. Lincoln carries the resultant motion to a rotating member engaging a disk rotating at a constant speed. The value of the resultant

determines the distance from center at which the rotating member engages the disk, thus the volt-ampere value is integrated. If this were a practical arrangement it would seem to be ideal, since he obtains a value proportional to the integrated square root of the sum of the squares.

The Sangamo Company is producing in Canada its watt-hour meter combined with the Lincoln volt-ampere demand meter as described for use with phase shifting transformer. Combining as this instrument does a registration of kilowatt-hours and volt-ampere demand it is said to be meeting with hearty approval in Canada. Last years report shows some 1500 volt-ampere-demand meters in use in Canada.

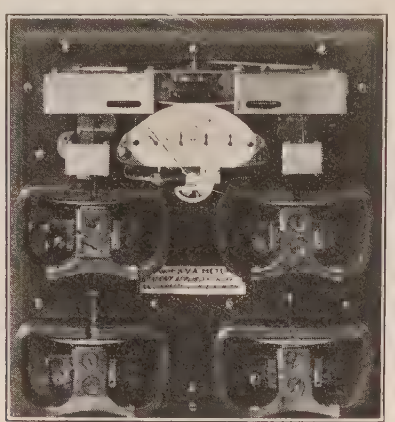

Fig. 5—Kv-a Demand and Kilowatt Hour Meter

Possibly the latest volt-ampere-demand meter on the market is the Sperti-Blecksmith meter being manufactured by the Westinghouse Company. The actual construction of this meter is shown in Fig. 5. As shown the meter is designed to register kilowatt-hours and 15 minute block interval volt-ampere-demand. The meter uses standard watt-hour current and potential elements, —no special windings being required.

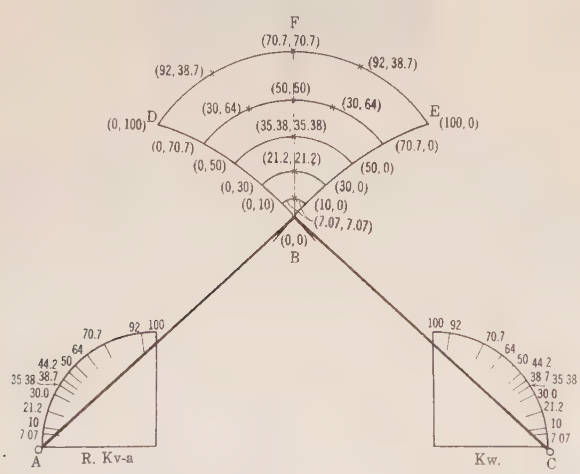

Fig. 6—Diagram Showing Accuracy of Kv-a. Meter

The rotation of the two right disk sare proportional to kilowatt-hour and the rotation of the two left disks are proportional to r. kv-a-h. The shafts are connected to two arms operating a pantograph, the centre point of which is connected through a flexible lead to the kv-a. demand indicator which indicates the resultant value of the in phase and reactive components—*i. e.* the square root of the integrated kw. and r. kv-a. for the interval of time for which the meter may be designed. Further details of operation are shown in Fig. 6.

The reactive meter is so connected to the pantograph that its integrated value is constant in direction for all ranges of power factor, leading or lagging; therefore the standard meter elements are operative over 100 per cent range in power factor. The inherent errors are small, and being constant in progression have easily been cancelled so that the meter compares in accuracy well with the standard watt-hour meter.

It is seen from the foregoing that quantity production on volt-ampere, volt-ampere-hour or volt-ampere-demand meters merely awaits a consistent demand.

Several large utilities have made, are making and are arranging to make contracts on a volt-ampere-demand basis.

It seems safe to assume or predict that during the next few years the volt ampere or "kv-a." meter will have taken its deserved place on a plane equal at least to the present kw. demand meter.

ARC REGULATION IN ELECTRIC FURNACES

In any furnace where two or more electrodes are used, one of the main problems in operation is the proper regulation of the electrodes. There are now available on the market a number of automatic control systems which, when functioning properly, give excellent regulation and an even, well-balanced load. These automatic regulators are expensive, however, and for small furnaces are often cumbersome and impractical, so that a large proportion of the furnaces are and probably will continue to be hand-operated. The principal objects of regulation are to maintain the correct power input, and to prevent surges and large fluctuations in the power. In furnaces depending on hand control, the operator regulates the power by observing ammeters or wattmeters placed within his line of vision from the controls, and moving the electrodes up or down accordingly. On the whole the prevention of fluctuations is done more out of consideration for the power plant than for the furnace itself. However, there is another phase of regulation, not so often mentioned, which is of greater importance to the melter in the proper operation of the furnace, namely, keeping equal arcs on the various electrodes. Details of experiments regarding arc regulation in electric furnaces and pilot light control are contained in Serial 2411, by C. E. Sims, electrometallurgist, which may be obtained from the Bureau of Mines, Washington, D. C.

The "Heavisidion"

A Computing Kinematic Device for Long Transmission Lines[1]

BY VLADIMIR KARAPETOFF

Fellow, A. I. E. E.

Professor of Electrical Engineering, Cornell University

Subject of the Paper.—*A kinematic computing device is described which can be set to represent vectorially the voltage and the current at any point of a long transmission line with uniformly distributed properties and with a given load. The device has been named after Oliver Heaviside who was among the first to establish and to solve the fundamental differential equations of such a line. The parts of the device are made to assume at will different positions corresponding to different points on the line. The constants of a line to be represented by the device are adjustable at will, and a complete set of performance curves of a given transmission line can be obtained. Conversely, by a few simple trials, the best constants of a line and the necessary kv-a. of a synchronous condenser may be found, to give the required performance characteristics. The current, the voltage, and the power factor (or the phase angle) can be read off directly on the device for any desired point of the line, including the generator and the load end.*

Results of computations are shown for two transmission lines, 1000 and 300 miles long, values having been obtained in the usual tedious way by means of hyperbolic functions of a complex variable, and also read off directly on the Heavisidion. The agreement is as good as could be desired, showing that the device is reliable and that a considerable saving in time is possible with it. The device consists mainly of steel and celluloid bars, proportional dividers, parallel double tongs, and other simple kinematic linkages. Two sharp-edged wheels are used, similar to those used in planimeters. The parts are so combined as to satisfy the familiar exponential vectorial expressions for the sinusoidal voltage and the current, the independent variable being the distance from one of the ends of the line.

A. Introduction

The Meaning of the Word Heavisidion. The device was named after the noted English scientist and engineer, Oliver Heaviside, Honorary Member of the A. I. E. E., who was among the first to establish and to solve the fundamental differential equations of an electric line with distributed resistance, inductance, capacitance, and leakance.

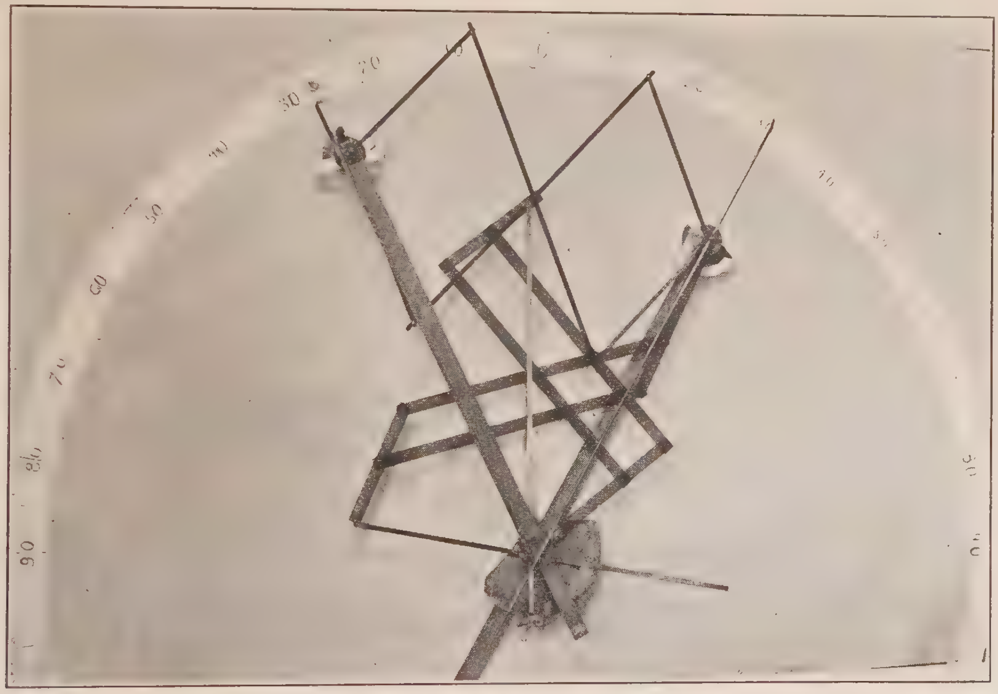

Fig. 1—The First Experimental Heavisidion

What the Heavisidion is. A combination of movable bars and linkages (Figs. 1 and 2) which can be set to represent, to a certain scale, the current and the voltage at any point of a line as vectors, in their proper relative phase position. The line constants are taken into account by properly setting the adjustable portions of the device. The parts of the device are kinematically so constrained that when it is set correctly for one point of the line, say the receiving end, it gives correct values for any other point. Each degree on the large circular scale corresponds to a certain number of miles along the line. By moving the two pointers by the same number of degrees in the opposite direc-

1. The investigation upon which this paper is based was supported by a grant from the Heckscher Foundation for the Advancement of Research, established by August Heckscher at Cornell University.

To be presented at the Midwinter Convention of the A. I. E. E., New York, N. Y., February 14-17, 1923.

tions, the device is reset for another desired point on the line.

The Purposes of the Device. (1) To enable a designer to predetermine quickly and accurately the voltage and current characteristics of a transmission line, at any desired load and terminal voltage, taking the distributed capacitance and leakage correctly into account; without hyperbolic functions, without complex quantities, and without short-cut approximate methods. (2) To enable a designer or an operating engineer to determine quickly the effect of a proposed change in the line constants, in the load, in the voltage, in the length of the line, etc., upon the resulting distribution of current and voltage along the

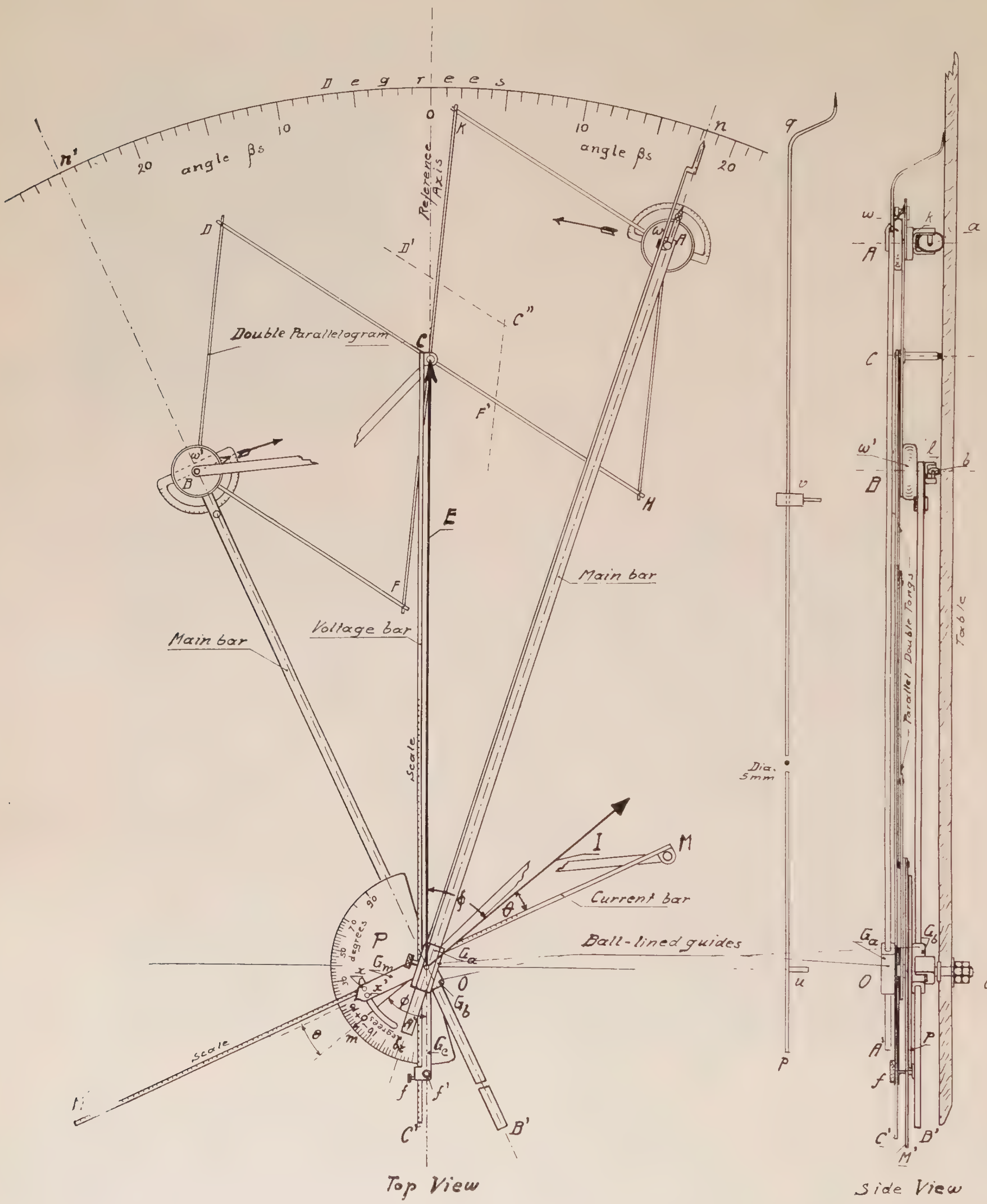

Fig. 2—The Top View and the Side View of the Heavisidion with the Parallel Double-Tongs Left Out (See Figs. 1 and 4.)

line. (3) To make it possible to select the proper kv-a. of a synchronous condenser at a desired point of the line, so as to obtain the desired line voltage characteristics. (4) For some purposes to take the place of the involved analytical theory and to permit to visualize the actual electrical relationships along the line. (5) To add the judgment of the eye and the skill of the hands to the purely mental ability in studying a line problem for which the device can be used. (6) To enable an investigator or a student to familiarize himself with the line characteristics (under steady conditions) as if an artificial line of widely adjustable constants, and any desired load and voltage, were available for tests.

Other Kinematic Devices. The Heavisidion is one of the several kinematic devices developed by the writer, for representing the performance characteristics of various kinds of electrical machinery and circuits. The other devices are as follows:

1. A device for representing the performance of an electromagnetic clutch used in the Owen magnetic car; *Sibley Journal of Engineering*, Jan. 1918, Vol. XXXII, p. 550.

7. A device for the study of transient phenomena in lines (in preparation).

Limits of Current and Voltage. Being a graphical device, the Heavisidion requires certain scales to be chosen for each particular problem. A convenient scale has to be selected for volts and another for amperes. The device can therefore represent the performance at a small load as well as at one which runs into hundreds of thousands of kilowatts; of an 11-kv. line as well as of one designed for 550 kilovolts. As in any graphical device, there may be some limitations due to the finite lengths of the bars, necessitating a change in the chosen scale. However, the device shown in Fig. 1 has been tested for lines up to 1000 miles long and found to be of sufficient accuracy, as will be seen from the second numerical example below.

B. General Description of the Heavisidion

The first complete Heavisidion, shown in Figs. 1 and 2, was built in the writer's experimental shop, in Cornell University, during the year 1922. Most parts are made of flat steel bars, or of celluloid bars, and the principal dimensions are given in the table below

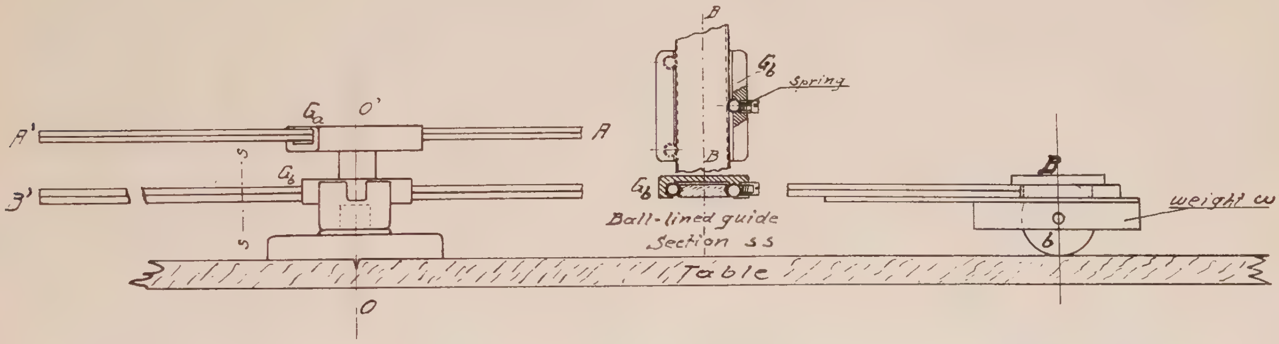

Fig. 3—A Side View Showing an Improved Center Piece Sliders and Wheel Support

2. The Secomor, a device which represents the performance of a polyphase series-connected commutator motor; A. I. E. E. Trans., 1918, Vol. XXXVII, Part I, p. 329.

3. The Indumor, a device which represents the performance of a polyphase induction motor, and its modification, the Shucomor, which represents the performance of a shunt-connected commutator motor; A. I. E. E. Journal, 1922, Vol. XLI, p. 107.

4. The Blondelion, a device which represents the operating characteristics of a polyphase synchronous generator or motor.

5. An Integraph based on parallel double-tongs, for a mechanical integration or differentiation of a given curve. This device finds its usefulness in problems of hunting of machinery, fly-wheel design, ship stability, etc. *Optical Soc. of Amer. and Review of Scientific Instruments, Journal*, 1922, Vol. VI, p. 978.

6. The C. P. S'er (named after Dr. C. P. Steinmetz), a device for the automatic addition of impedances and admittances (description in preparation).

In the writer's opinion, the size of the device could be considerably reduced without impairing its accuracy, if the instrument were made with the precision of, say, a planimeter. The grooved bars and the improved slider, shown in Fig. 3, are of about one-half the size of those shown in Figs. 1 and 2.

THE PRINCIPAL DIMENSIONS OF THE HEAVISIDION

Part or distance (Fig. 2)	Length in cm.	Cross-sec. in mm.
Circular scale, radius	80	..
Bars $A\ A'$ and $B\ B'$	80	25 × 3
Bars $C\ C'$ and $M\ M'$	65	10 × 1.5
Bars $D\ H$ and $F\ K$	60	10 × 1.5
Bars $B\ D$, $B\ F$, $K\ A$ and $A\ H$	30	10 × 1.5
Rod $p\ q$	80	5 (dia.)
Sharp-edged wheels, dia.	..	25 and 12

The Voltage. In the side view (Figs. 2 and 3) $O\ O'$ is a vertical axis about which the guide sleeves G_a and G_b can revolve. In the top view the steel bars $A\ A'$ and $B\ B'$ are shown passing through these guides. Each guide is lined on the inside with steel balls to reduce the

friction to the movement of the bars (Fig. 3). A fork k (Fig. 2) is pivoted about a vertical axis at A and serves as a bearing for the sharp-edged wheel a which can roll on the horizontal table which supports the device. By means of the protractor shown at A, the vertical plane of the wheel a may be set at any desired angle to the longitudinal center line of $A\,A'$. A similar fork l guides the sharp-edged wheel b at B. The weights w and w' provide a sufficient pressure between the wheels and the table to prevent the wheels from slipping sidewise. A somewhat different type of wheel support is shown in Fig. 3.

When the bar $A\,A'$ is being rotated about $O\,O'$ as an axis, the wheel a rolls on the table and acts as a rudder for the bar, pushing the end A towards O or pulling it away from O, depending upon the setting of the plane of the wheel and the direction of rotation (Fig. 8). Thus, as the bar $A\,A'$ rotates, it also slides within the guide G_a, and the effective length $O\,A$ varies. The same applies to the bar $B\,B'$. The guides G_a and G_b are provided with setscrews by means of which each bar can be fastened to its guide and prevented from sliding.

The points A and B are connected by means of the articulated double parallelogram $A\,K\,H\,C\,D\,F\,B$, so that point C is always midway on the straight line connecting A and B. The vector of the line voltage E at any point is represented by the direction and magnitude of $O\,C$. When the length $O\,C$ varies, the bar $C\,C'$ slides freely through the guide sleeve G_c pivoted at O. By means of the setscrew f the length $O\,C$ may be fixed, if so desired, when first setting the device. The length $O\,C$, in cm., can be read directly on the scale marked on the bar $C\,C'$.

The angular position of the bar $A\,A'$ on the large circular scale is indicated by the pointer $O\,n$, pivoted at O. To indicate the angular position of $B\,B'$ and $C\,C'$, a detachable pointer $p\,q$ is used. The stationary pin u fits into a hole at the center of the guide G_a; the adjustable pin v may be shifted along the pointer and set to fit a hole either at B or at C. As the distance of B (or of C) from O varies, the pointer $p\,q$ slides through the hole in v, and the length of the vector may be read on the scale.

The Current. It is proved below, in the theory of the device, that the line current is proportional to the length $A\,B$, and that the vector I of the current forms a constant angle θ with the direction $B\,A$; this angle depends only upon the line constants, but not upon the voltage or the load. It would be rather inconvenient to determine the length and the direction of $A\,B$ for every setting of the device and to make a correction for θ. For this reason a definite portion of the vector $B\,A$ is transferred parallel to itself to the bar $M\,M'$, as the vector $O\,M$. This bar slides in the guide G_m, also pivoted at O. The guide G_m is provided with the setscrew x, by means of which the length $O\,M$ may be fixed in the original setting of the device. The length $O\,M$, in cm., can be read directly on a scale marked on the bar $M\,M'$. The angular position of $O\,M$ may be read on the protractor P, or more accurately on the large outer scale, by applying the pointer $p\,q$.

In the particular Heavisidion shown in Figs. 1 and 2 it has been found convenient to make $O\,M$ equal and parallel to $B\,C$ or $C\,A$. For this purpose the author's parallel double tongs are used[2] shown separately in Fig. 4, and also shown connected in Fig. 1. This kinematic linkage is fastened by means of pivots at points B, C, O, and M (only the beginnings of the bars being shown in Fig. 2, so as not to obscure the sketch) and constrains the vectors $B\,C$ and $O\,M$ to remain equal and parallel to each other, without imposing any other limitations as to their direction, magnitude, or position in the plane of the device. The parallel double tongs are shown in Fig. 4 in two positions. At

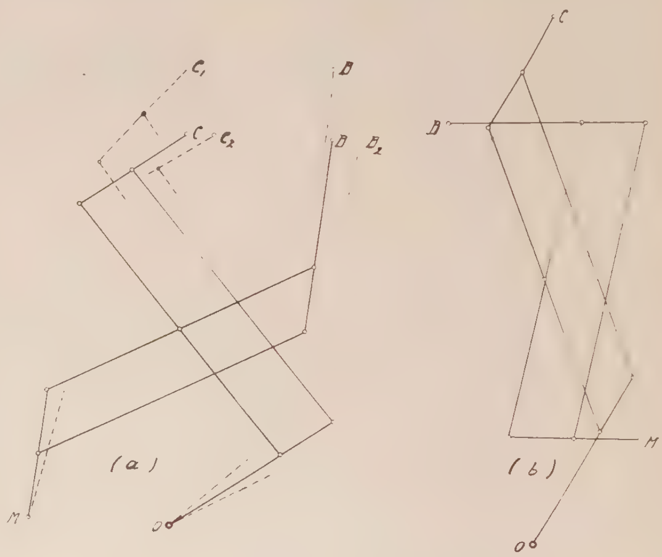

Fig. 4—Parallel Double Tongs

(a) they are shown open, as in Fig. 1, and at (b) crossed as they are in the position of the bars $A\,A'$ and $B\,B'$ in Fig. 2.

The protractor P is pivoted at O and provided with a slot. Through this slot the guide G_m can be fastened to the protractor at a desired angle θ, by means of the setscrew x'. The guide G_c can also be fastened to the protractor by means of the setscrew f', when first setting the device. Later this setscrew is loosened and the phase angle between the voltage and the current is read on the protractor at the notch on G_c. The protractor may be graduated both in degrees and in values of power factor. With no leakage or with small leakage, the angle θ should be set in the direction indicated in the sketch, but the slot is long enough to allow a setting of G_m on the other side of the zero division.

With the parallel double tongs attached at C, the current scale is fixed. Should it be desired to make this scale independent of the voltage scale, an adjust-

2. *American Machinist*, 1921, Vol. 55, p. 1050.

able link $D' C'' F'$ may be added to the double parallelogram and the connection to the parallel double tongs made at C'', instead of C. It is also possible to turn the vector $O M$ by the angle θ so as to represent the true phase position of the current. This can be done, for example, by using the generalized proportional dividers described in the paper on the Indumor (*loc. cit.*, p. 111).

C. Auxiliary Charts of Line Constants

In order to use the Heavisidion for a line of given current vector I, Figs. 2 and 7; it is proposed to call this angle the *differential angle* of the line.

z_s, the *surge impedance* of the line, which determines the scale of the line current;

β, the *wave length constant* of the line.

The angle β is the angle by which each of the bars, $A A'$ and $B B'$, must be turned (in the opposite directions) in order to obtain a setting for a point of the line one km. or one mile distant from the given setting. In other words, β is measured in degrees (or radians)

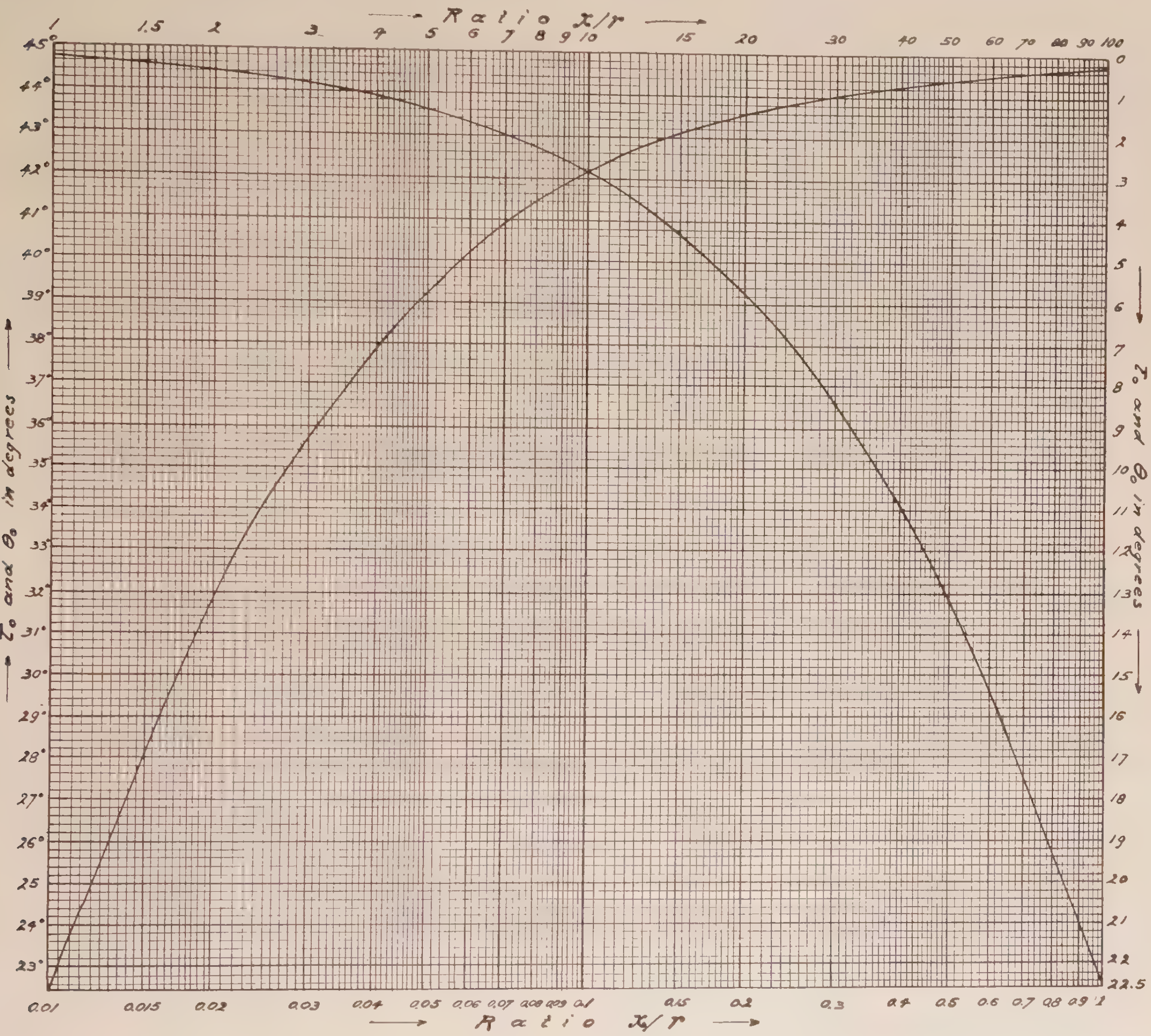

Fig. 5

Fig. 5—A Chart of Values of Imperfection Angle τ_0 and of Differential Angle θ_0 for Lines of Zero Leakage ($g = 0$); in this Case $\theta_0 = \tau_0$. *Examples:* $x/r = 3$, $\tau_0 = 10$ deg. 13 min.; $x/r = 0.4$, $\tau_0 = 34$ deg. 06 min.

constants (resistance, reactance, capacitance and leakance, all per unit length), it is necessary to determine the following auxiliary constants (see also the list of symbols at the end of the paper):

τ, the so-called *imperfection angle* of the line; the sharp-edged wheels a and b are set at this angle (Fig. 8).

θ, the angle between $O M$ and the true direction of per unit length. If β is measured in degrees, then (360 deg./β deg) gives the number of miles for which each of the bars is turned by 360 deg. The bars are then again in their original positions and the values of current and voltage repeat themselves. The length 360 deg./β deg. is therefore called the wave length of the line; it depends upon the line constants and the

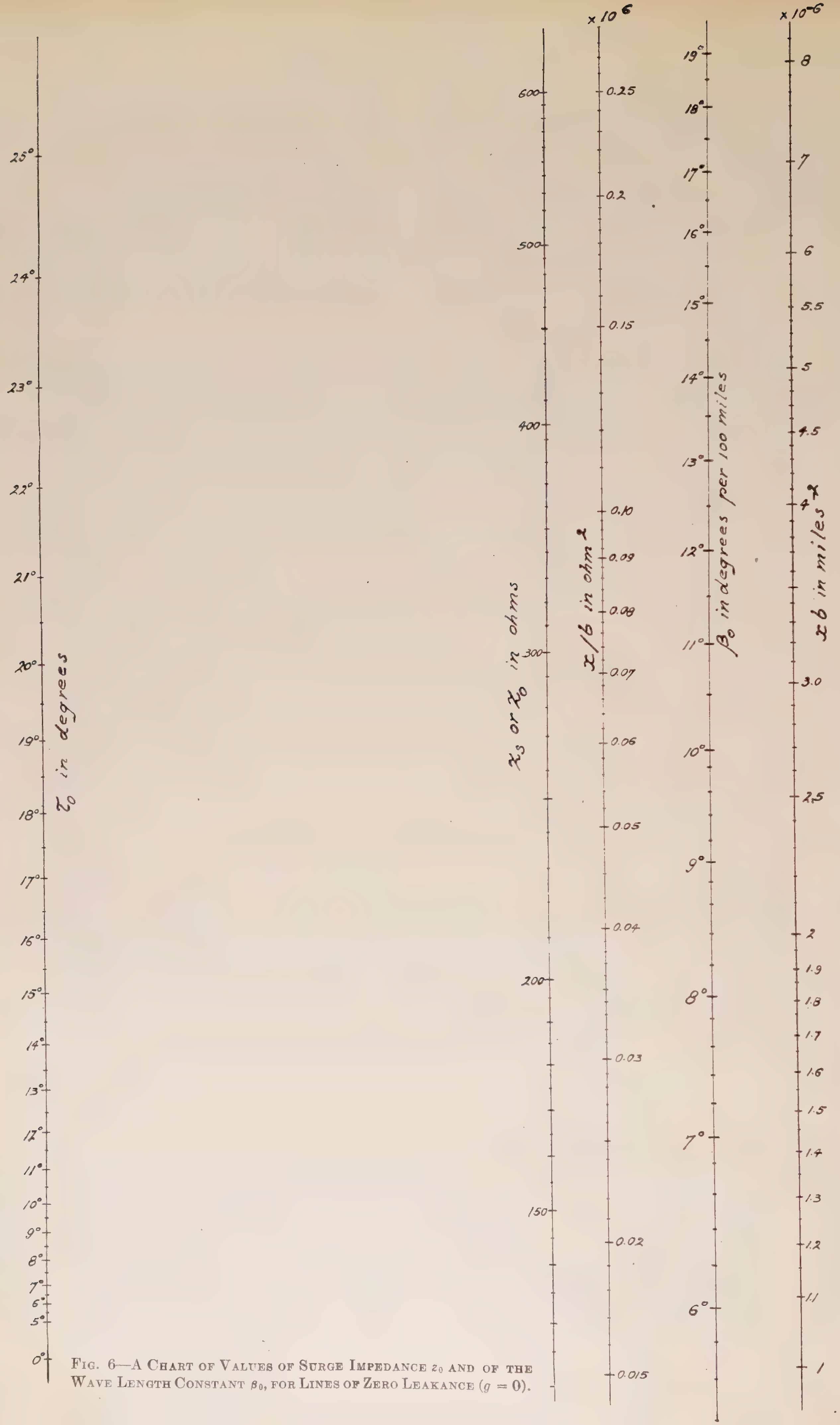

Fig. 6—A Chart of Values of Surge Impedance z_0 and of the Wave Length Constant β_0, for Lines of Zero Leakance ($g = 0$).

frequency. In the actual use of the Heavisidion it has been found convenient to compute the value of β directly for each 100 miles, so as to avoid small quantities; this should be kept in mind when using the values of β_0 found from Fig. 6.

In most practical cases of long-distance high-tension transmission lines the distributed leakage is negligible. The symbols for the foregoing four constants are then provided with the subscript zero. Thus, τ_0, θ_0, z_0 and β_0 are the values corresponding to zero leakage. These values may be obtained directly from the charts shown in Figs. 5 and 6, without any computations. In rare cases when the leakage has to be considered, a small correction is necessary, as is explained below.

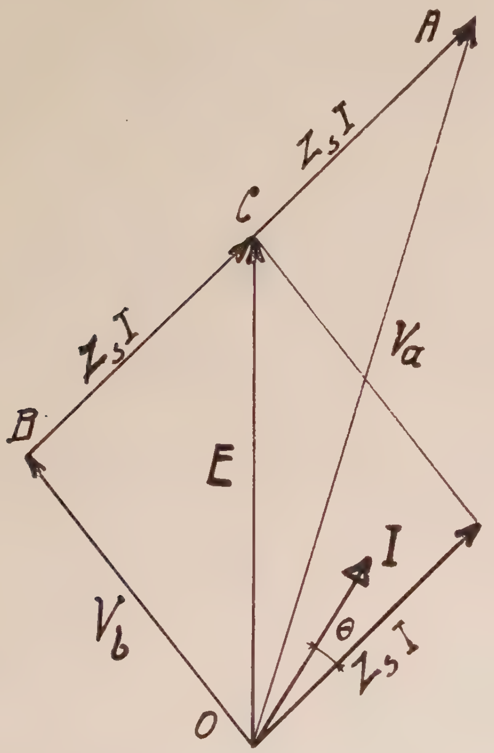

FIG. 7—THE RELATIONSHIP BETWEEN THE COMPONENT VOLTAGES V_a AND V_b, THE TOTAL VOLTAGE E, AND THE VECTOR $Z_s I$.

Knowing the size and the material of the line conductors, their spacing, and the frequency of the supply, the following quantities *per phase per mile* can be either computed or taken directly from tables available in various handbooks, etc.:

r the effective resistance, in ohms per mile;
x the inductive reactance, in ohms per mile;
b the capacitive susceptance, in mhos per mile.

The tables arranged by Mr. Wm. Nesbit and published in *The Electric Journal*, 1919, Vol. XVI, pp. 317 to 322, will be found convenient in that the ratio x/r is tabulated directly. These tables will be also found in the "Electrical Characteristics of Transmission Circuits," *Reprint* 82, Feb. 1922, on pages 12 to 19 (published by the Westinghouse Electric & Manufacturing Co.).

Knowing x/r, the values of θ_0 and τ_0 (which are equal to each other for a line devoid of leakage) can be read off directly on the chart in Fig. 5. To find z_0, it is necessary first to compute the ratio x/b. Referring to Fig. 6, a straight edge is then placed between the known values of τ_0 and x/b on the corresponding scales, and the value of z_0 is read off on the second scale from the left. Then the product $x\,b$ is computed and the straight edge is laid between the proper values of τ_0 and $x\,b$ on the outside scales. The corresponding value of β_0 is read off on the second scale from the right.

D. THE USE OF THE HEAVISIDION AND NUMERICAL EXAMPLES

Example 1. On p. 103 of the above mentioned *Reprint* of Nesbit's articles, or in the *Electric Journal*, 1920, Vol. XVII, p. 300, the following example is given: A three-phase, 60-cycle, 300-mile, transmission line; No. 000 stranded copper conductor spaced 10 by 10 by 20 ft. (equivalent delta 12.6 ft.); temperature 25 deg. cent. The receiver load is 18,000 kv-a. at 90 per cent power factor, lagging; the receiver voltage is 104 kv. It is required to determine the voltage, the current, and the power factor at the generator end. The line leakage is to be neglected.

Preliminary Computations. (a) The receiver voltage to the neutral is $E_2 = 104\sqrt{3} = 60.05$ kv; the receiver current per phase is $I_2 = 18000/(3 \times 60.05) \doteq 99.92$ amperes. The corresponding phase angle is $\phi_2 = \cos^{-1} 0.90 = 25$ deg. 50 min.

(b) For the given conductor and spacing we find by interpolation the following values per phase:

Reprint No. 82.	*Electric Journal* 1919, Vol. XVI.			
page 13	page 317	table V	x	$= 0.83$ ohm per mile
page 15	page 319	table VII	x/r	$= 2.37$ numeric
page 18	page 322	table X	b	$= 5.21$ micro-mhos.

Hence, $x\,b = 4.24 \times 10^{-6}$ miles^{-2}; $x/b = 0.159 \times 10^6$ ohm^2.

(c) Using these values, we find from the charts in Figs. 5 and 6, as explained above: $\tau_0 = \theta_0 = 11$ deg. 26 min.; $z_0 = 416$ ohms; $\beta_0 = 12.2$ deg. per 100 miles.

Setting of the Heavisidion. (d) Select a convenient voltage scale; in this particular case it was taken as 3 kv. per cm. Set $C\,C'$ (Fig. 2) along the reference line marked on the table and make $O\,C = 60.05/3 = 20.02$ cm.; tighten the setscrew f. When setting the point C, it is necessary to move points A and B and therefore the bars $A\,A'$ and $B\,B'$. This adjustment should be made carefully and the wheels a and b slightly lifted by holding the device at C, so as not to scratch the table.

(e) By means of the protractors at A and B, set the wheels a and b at the angle $\tau_0 = 11$ deg. 26 min. in such a direction (Fig. 8) that the lengths $O\,A$ and $O\,B$ (Fig. 2) will increase when the bars are rotated counterclockwise.

(f) Set the slide G_m at the angle $\theta_0 = 11$ deg. 26

min., in the direction marked + on the protractor P, and set the protractor P at the angle $\phi_2 = 25$ deg. 50 min. to the voltage bar $C\,C'$. This means that the actual angle between the bars $C\,C'$ and $M\,M'$ is 25 deg. 50 min. + 11 deg. 26 min. = 37 deg. 16 min., although the reading on P is only 25 deg. 50 min.

(g) The current scale is determined by the voltage scale and by the previously found value of z_0. Namely, with 3000 volts per cm., the current scale is, 1 cm. = 3000/416 = 7.2 amperes. Therefore the length $O\,M$ = 99.92/7.2 = 13.9 cm.

(h) Tighten the setscrew x on G_m, and also the setscrews on G_a and G_β.

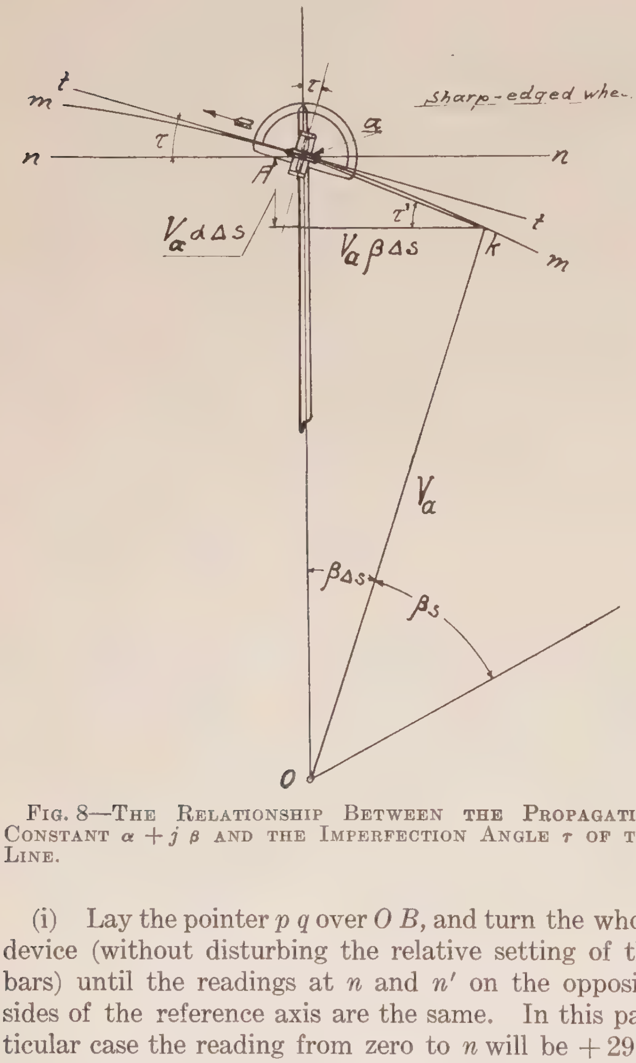

Fig. 8—The Relationship Between the Propagation Constant $\alpha + j\,\beta$ and the Imperfection Angle τ of the Line.

(i) Lay the pointer $p\,q$ over $O\,B$, and turn the whole device (without disturbing the relative setting of the bars) until the readings at n and n' on the opposite sides of the reference axis are the same. In this particular case the reading from zero to n will be + 29.5 degrees and from zero to n' − 29.5 degrees.

Readings. (j) The angle β_0 being 12.2 deg. per 100 miles and the length of the line 300 miles, the bars $A\,A'$ and $B\,B'$ have to be turned by 12.2 × 3 = 36.6 deg. each. The bar $A\,A'$ must be turned counter-clockwise until it comes to the scale division 36.6 deg. − 29.5 deg. = 7.1 deg. to the left of zero; point n' must come to 7.1 deg. to the right of zero. The bars $A\,A'$ and $B\,B'$ will have to cross each other; the double parallelogram and the parallel double tongs are mounted in different planes so as not to interfere with such motion. It is easier first to move one bar by a certain amount, leave it there, then move the other bar, etc.[3] In the final position of the bars, the lengths $O\,C$ and $O\,M$ are measured to the same scale as before, and we find that the generator voltage E_1 = 70.4 kv., the generator current I_1 = 96 amperes, and the phase angle ϕ_1 = 21 deg. 30 min., with the current leading.

(k) If it is required to find the current and the voltage at several points along the line, say every 50 miles, the bars $A\,A'$ and $B\,B'$ are moved by an angle of 12.2/2 = 6.1 deg. at a time, and readings are taken as before.

In the following table the "primed" values are those read off on the Heavisidion, while the unprimed values have been computed by means of hyperbolic functions (*Reprint*, p. 105, or *The Electric Journal*, 1920, Vol. XVII, p. 309). It will be seen that even with a purely tentative device, built without any claim at precision, the agreement is quite satisfactory.

L miles	E kilovolts	E'	I amperes	I'	ϕ	ϕ'	Current
0	60.05	60.05	99.92	99.92	25 deg. 50 min.	25 deg. 50 min.	lags
50	63.17	63.50	93.66	93.30	19 deg. 53 min.	19 deg. 40 min.	"
100	65.77	66.00	88.94	88.0	12 deg. 34 min.	12 deg. 30 min.	"
150	67.81	68.20	86.37	86.5	4 deg. 14 min.	4 deg. 00 min.	"
200	69.31	69.80	86.47	87.5	4 deg. 42 min.	4 deg. 10 min.	leads
250	70.24	70.00	89.33	90.0	13 deg. 18 min.	12 deg. 30 min.	"
300	70.65	70.40	94.75	96.0	20 deg. 53 min.	21 deg. 30 min.	"

Example 2. In Pernot's "Electrical Phenomena in Parallel Conductors," 1918, Vol. I, p. 101, a three-phase, 60-cycle transmission line is quoted for which the linear constants *per mile per phase* are as follows: r = 0.275 ohm; x = 0.769 ohm; $b = 5.51 \times 10^{-6}$ mho; $g = 0.15 \times 10^{-6}$ mho. This example differs from the preceding one in that the leakance g is not equal to zero, although it is quite small. Proceeding as before, on the assumption of $g = O$, we find from Figs. 5 and 6 the following values: $\tau_0 = \theta_0$ = 9 deg. 50 min.; z_0 = 385 ohms, and β_0 = 23.95 deg. per 100 miles.

In order to correct for the effect of the leakage, we compute the leakage angle θ_g, from the relationship tan $\theta_g = g/b$ = 0.15/5.51. See eq. (**18**) below.

This gives θ_g = 1 deg. 34 min.; with this value we correct the above obtained values as follows. See *Correction for Small Leakage* at the end of the paper:

$\tau = \tau_0 + 0.5\,\theta_g$ = 9 deg. 50 min. + 0.5 × 1 deg. 34 min. = 10 deg. 37 min.;

$\theta = \tau_0 - 0.5\,\theta_g$ = 9 deg. 50 min. − 0.5 × 1 deg. 34 min. = 9 deg. 03 min.;

$\beta = \beta_0\,(\cos\tau/\mathrm{Cos}\,\tau_0)$ = 23.95 (0.9829/0.9853) = 23.9 deg. per 100 miles.

It will thus be seen that with a small angle θ_g the correction for β is negligible. The same is true for the

3. An additional kinematic connection could be added between the bars $A\,A'$ and $B\,B'$ to constrain them to move simultaneously by the same angle in the opposite directions, should a special problem warrant such a complication.

surge impedance z_s; with small leakage it may be taken as equal to z_0 without leakage.

Knowing the above constants, the Heavisidion was set for a given receiver load and voltage, and by moving the bars in steps of 200 miles the "primed" values were obtained given in the table below.

L miles	E kilovolts	E'	I amperes	I'	ϕ	ϕ'	Current
0	50.0	50.0	25.0	25.0	25 deg. 00 min.	25 deg. 00 min.	lags
200	48.8	49.3	49.8	50.7	58 deg. 33 min.	58 deg. 15 min.	leads
400	40.7	40.05	94.7	95.0	65 deg. 09 min.	65 deg. 00 min.	leads
600	28.9	29.0	128.5	128.5	50 deg. 01 min.	50 deg. 00 min.	"
800	24.3	24.6	143.7	146.0	10 deg. 24 min.	9 deg. 00 min.	"
1000	34.7	36.0	140.0	142.5	19 deg. 21 min.	18 deg. 30 min.	lags

The unprimed values were computed by Mr. Pernot using exponential expressions (*ibid.*, p. 107). Here again the agreement between the computed and measured values is quite satisfactory, especially considering the great length of the line.

Procedure with Extra-Long Lines. The circular scale of the Heavisidion as actually built (Fig. 1) extends only up to about 100 deg. on each side of the center zero. Therefore, for an extra-long line, or at a high frequency, the bars $A A'$ and $B B'$ (Fig. 2) may be at the limits of the scale before the other end of the line has been reached. In such a case the Heavisidion is used as *its own optical image.*

Referring again to Fig. 1, let the pointers of the main bars be somewhere on the lower (non-existing) semicircle of the scale. Imagine a plane vertical mirror passing through both 90 deg. points and the center line $O O'$ of the device, the reflecting plane being turned towards the fictitious semicircle. The optical image of such an impossible setting lies in the upper semicircle, and therefore can be realized on the actual device, being in its real range. While the bar $A A'$ moves counter-clockwise, its image moves clockwise. The reverse is true for the bar $B B'$.

Therefore, when the bars get near or past the 90 deg. points, proceed as follows: Tighten the setscrews of guides G_a and G_b, and note the amount by which the bars have passed the 90 deg. points, for example, $+\rho_1$ and $-\rho_2$ degrees, respectively. Turn the wheels a and b by the angle τ on the other side of zero so that the lengths $O A$ and $O B$ would increase if rotated clockwise. Move the bars to the positions corresponding to $-\rho_1$ and $+\rho_2$ degrees with respect to the 90 deg. points. Loosen the setscrews and continue moving each bar in the direction opposite to its previous motion. By this means the range of the device can be increased indefinitely.

Branch Loads. Let the Heavisidion be set for the receiver end and then the bars $A A'$ and $B B'$ rotated towards the generator end, as explained above. Let there be a branched concentrated load somewhere on the line. Having come to this point, the voltage bar $C C'$ is fastened so that it cannot move, while the current bar $M M'$ and the bars $A A'$ and $B B'$ are reset to take into consideration the added branch current. Then the motion of the device is resumed as heretofore, to the next load, where the new current is added vectorially, etc.

Synchronous Condenser. Usually a very long transmission line has to have a synchronous condenser at the receiver end, in order to keep voltage fluctuations within reasonable limits. The required maximum kv-a. of such a condenser can be determined with the Heavisidion by a few simple trials. The device is set for the desired receiver voltage and for a reasonable reactive current to be supplied by the condenser, in addition to the load current. Then the bars $A A'$ and $B B'$ are turned into the position corresponding to the generator end, and the results noted. If the generator voltage is not satisfactory, the device is reset at the receiver end for a different reactive component and the new generator voltage measured. In this manner, the limits of the required reactive current are found after a few simple trials, without any complicated computations.

E. Theory of the Heavisidion

The well-known fundamental equations of the sinusoidal alternating current and voltage in a transmission line, at a point distant s miles from the receiver end, are as follows:[4]

$$E = 0.5\,(E_2 + Z_s I_2)\,\epsilon^{\alpha s}\,\epsilon^{j\beta s} + 0.5\,(E_2 - Z_s I_2)\,\epsilon^{-\alpha s}\,\epsilon^{-j\beta s} \quad (1)$$

$$I = 0.5\,(E_2 Z_s^{-1} + I_2)\,\epsilon^{\alpha s}\,\epsilon^{j\beta s} - 0.5\,(E_2 Z_s^{-1} - I_2)\,\epsilon^{-\alpha s}\,\epsilon^{-j\beta s} \quad (2)$$

For the meaning of the symbols see the list at the end of the paper. Multiplying eq. (2) by Z_s gives

$$Z_s I = 0.5\,(E_2 + Z_s I_2)\,\epsilon^{\alpha s}\,\epsilon^{j\beta s} - 0.5\,(E_2 - Z_s I_2)\,\epsilon^{-\alpha s}\epsilon^{-j\beta s} \quad (3)$$

Combination of E and $Z_s I$ out of V_a and V_b. Let us introduce, for the sake of abbreviation, component voltages V_a and V_b, where

$$V_a = (E_2 + Z_s I_2)\,\epsilon^{\alpha s}\,\epsilon^{j\beta s} \quad (4)$$

$$V_b = (E_2 - Z_s I_2)\,\epsilon^{-\alpha s}\,\epsilon^{-j\beta s} \quad (5)$$

For a given point on the line, V_a and V_b are vectors measured in effective volts. Eqs. (1) and (3) become

$$E = 0.5\,(V_a + V_b) \quad (6)$$

$$Z_s I = 0.5\,(V_a - V_b) \quad (7)$$

These relations are shown graphically in Fig. 7.

4. See, for example, C. P. Steinmetz, "Transient Phenomena," Section III, Transients in Space; F. E. Pernot, "Electrical Phenomena in Parallel Conductors," pp. 96-98. In the following equations the customary dots under E and I, to denote vectors, are omitted.

V_a is a geometrical sum and V_b a geometrical difference of E and $Z_s I$; that is,

$$E + Z_s I = V_a \qquad (8)$$

$$E - Z_s I = V_b \qquad (9)$$

Adding these equations and dividing by 2, eq. (6) is obtained; subtracting and dividing by 2, gives eq. (7).

Thus, the voltage E at a point on the line can be formed out of the vectors V_a and V_b for the same point. Similarly, the vector $Z_s I$ can be formed in a different manner out of the same vectors. But for a given line Z_s is a known constant, see eqs. (26) to (29) below. Therefore, knowing $Z_s I$, the current vector I can be obtained. Z_s, being a complex quantity, is characterized by its magnitude z_s and the phase angle θ. Therefore, to obtain I, the vector $Z_s I$ must be divided by z_s and turned by the angle θ.

Comparing now Figs. 7 and 2, it will be seen that the bars $A A'$ and $B B'$ represent the voltages V_a and V_b respectively. The double parallelogram between A and B fixes the point C and thus determines both E and $Z_s I$. By means of the parallel double tongs, $Z_s I$ is transferred to $O M$, and the angle θ is taken into consideration in the setting of the guide G_m with respect to the zero mark on the protractor P.

Variation of V_a and V_b with s. At the receiver end ($s = 0$) eq. (4) gives

$$V_{ar} = E_2 + Z_s I_2 \qquad (10)$$

Hence, at any point on the line

$$V_a = V_{ar}\, \epsilon^{\alpha s}\, \epsilon^{j\beta s} \qquad (11)$$

Geometrically interpreted, this means that the vector V_a may be obtained from V_{ar} by changing the magnitude of the latter in the ratio of $\epsilon^{\alpha s}$: 1, and by turning it counter-clockwise by the angle βs.[5]

A sharp-edged wheel a (Figs. 2 and 8), set at a proper angle τ at A, accomplishes the desired purpose. As the bar $A A'$ is being turned counter-clockwise about O, the wheel a rolls on the table and forces the point A away from O. The wheel tracks a logarithmic spiral and consequently causes the length $O A$ to increase in a geometric progression, when the angle βs increases in an arithmetical progression.[6]

In order to express the angle τ through α and β (Fig. 8), let $m\,m$ be a small portion of the curve traced by the wheel a on the table. Let $t\,t$ be a tangent to the curve at A, and let $A\,k$ be a small arc of the curve which practically coincides with the chord $A\,k$. Let $O\,k$ represent the value of V_a at k; then $O\,A$ is the increased value of V_a due to an increase $\beta\,\Delta\,s$ in the angle $\beta\,s$. Here $\Delta\,s$ is a small element of length along the transmission line. The angle which the tangent to the curve makes with $n\,n$ (perpendicular to $O\,A$) is denoted by τ. This angle has been called the imperfection angle of the line.[7] For a line devoid of resistance and leakage, $\tau = 0$ and the end of the vector V_a describes a circle.

The line $c\,k$ is drawn at right angles to $O\,A$, that is, parallel to $n\,n$. The angle at k is not quite equal to τ, but approaches this value as the point k indefinitely approaches A. Let the angle at k be called τ'. When the angle $\beta\,\Delta\,s$ is very small, $k\,c$ practically coincides with the arc $k\,c$ of radius V_a, drawn from O as a center. Therefore, in the limit, replacing $\Delta\,s$ by $d\,s$, we have

$$k\,c = V_a\,\beta\,d\,s \qquad (12)$$

The increment in the length of the vector V_a, that is, the algebraic difference between $O\,A$ and $O\,k$, is approximately equal to $c\,A$, since, with a small angle $\beta\,\Delta\,s$, $O\,k$ is nearly equal to $O\,c$. But the increase in the length of V_a, apart from the change in the direction, is equal to

$$\Delta\,V_a = V_a\,\epsilon^{\alpha\Delta s} - V_a \qquad (13)$$

Expanding into a Maclaurin series, we get

$$\Delta\,V_a = c\,A = V_a\,(\epsilon^{\Delta\alpha s} - 1) = V_a\,[\alpha\,\Delta\,s + 0.5\,\alpha^2\,(\Delta\,s)^2 + \text{etc.}] \qquad (14)$$

When ultimately $\Delta\,s$ is reduced to an infinitesimal $d\,s$, all the terms of the expansion, except the first, can be neglected, and we get

$$c\,A = V_a\,\alpha\,d\,s \qquad (15)$$

Therefore, in the limit, when $\tau = \tau'$,

$$\tan\tau = \tan\tau' = c\,A/k\,c = \alpha/\beta \qquad (16)$$

The foregoing discussion, being based on eq. (4), applies to vector V_a. A similar result can be obtained for vector V_b on the basis of eq. (5), except that the exponents are negative; consequently the rotation is clockwise, and the vector decreases instead of increasing in magnitude. Thus, in order to obtain the values of V_a and V_b for different points on the line, the bars $A\,A'$ and $B\,B'$ (Fig. 2) must be moved in the opposite directions, each by the angle β per unit length of the line. The wheels a and b then automatically change the lengths of these vectors in the proper ratio. If the lengths and the positions of V_a and V_b have been properly selected at some one point of the line, they remain correct at any other point, thus justifying the construction of the device.

F. Theory of the Auxiliary Charts

The practical use of the Heavisidion is very much simplified by means of the charts shown in Figs. 5 and 6. The use of the charts is explained under C above, so that it remains only to review the theoretical

5. For the theory of the "turning operator," $\epsilon^{j\beta s} = \text{Cos}\,\beta + j\,\text{Sin}\,\beta$, see for example V. Karapetoff's "Electric Circuit," Arts. 33 and 34; also his paper on superimposed imaginary e. m. fs., in the A. I. E. E. Journal, 1922, Vol. 41, p. 11.

6. Pernot, *ibid.*, p. 114.

7. See V. Karapetoff, Trigonometric Expressions for the Phenomena Occurring in Long Transmission Lines; *Electrical World*, 1915, Vol. XLVI, pp. 857 and 914.

relationships of the various constants of a transmission line, in order to make clear the underlying theory of these charts. For the elementary theory of electric lines the reader is referred to numerous works on the subject, among others to those mentioned above.

The Imperfection Angle Expressed Through the Line Constants. The factors α and β can be expressed through the linear constants of the line; therefore the angle τ, eq. (16), can also be expressed through these constants. Referring to Fig. 9, we introduce the *resistance angle*, θ_r, defined by the expression

$$\tan \theta_r = r/x \tag{17}$$

and the *leakage angle*, θ_g, defined by

$$\tan \theta_g = g/b \tag{18}$$

For a line devoid of resistance and leakage $\theta_r = \theta_g = 0$. For the series impedance Z and the shunted admittance Y of the line, per unit length, we can therefore write

$$Z = z\, \epsilon^{j(0.5\,\pi - \theta_r)} \tag{19}$$

$$Y = y\, \epsilon^{j(0.5\,\pi - \theta_g)} \tag{20}$$

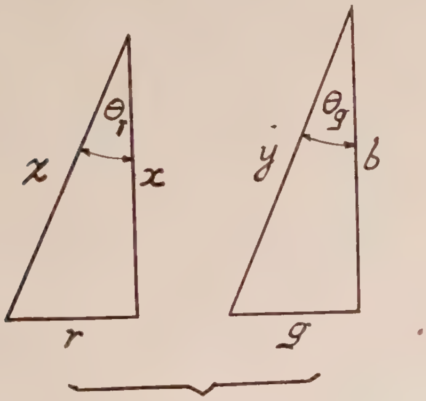

FIG. 9—THE RESISTANCE ANGLE AND THE LEAKAGE ANGLE OF THE LINE

For the complex propagation constant we have

$$\alpha + j\beta = \sqrt{ZY} = \sqrt{zy}\, \epsilon^{0.5\,\pi - 0.5\,j(\theta_r + \theta_g)} \tag{21}$$

Hence $\alpha = \sqrt{zy}\,\text{Sin}\, 0.5\,(\theta_r + \theta_g)$ (22a)

$$\beta = \sqrt{zy}\,\text{Cos}\, 0.5\,(\theta_r + \theta_g) \tag{22b}$$

In the expression for β it is sometimes convenient to use x and b in place of z and y. From Fig. 9 we have

$$z = x/\cos\theta_r\,;\; y = b/\text{Cos}\,\theta_g \tag{23}$$

The foregoing expression for β then becomes

$$\beta = \sqrt{\frac{x\,b}{\text{Cos}\,\theta_r\,\text{Cos}\,\theta_g}} \times \text{Cos}\, 0.5\,(\theta_r + \theta_g) \tag{24}$$

Substituting the values of α and β from eqs. (22) in eq. (16), gives

$$\tan \tau = \tan 0.5\,(\theta_r + \theta_g)$$

from which, since τ is less than 90 deg.,

$$\tau = 0.5\,(\theta_r + \theta_g) \tag{25}$$

Thus, knowing the angles θ_r and θ_g from eqs. (17) and (18), the imperfection angle τ, at which the wheels a and b must be set, can be computed from eq. (25), without first determining the values of α and β.

Surge Impedance and its Angle Expressed through the Line Constants. By definition, the surge impedance of a line

$$Z_s = z_s\, \epsilon^{-j\theta} = \sqrt{Z/Y} \tag{26}$$

where Z and Y are expressed by eqs. (19) and (20) respectively. Z_s is a complex quantity, and is characterized by its magnitude z_s and the phase angle θ. It is convenient to use the minus sign before θ, because in ordinary power transmission lines this operator turns the current vector clockwise; compare the directions of $Z_s I$ and I in Figs. 2 and 7. Substituting the values of Z and Y in eq. (26), we get

$$z_s\, \epsilon^{-j\theta} = \sqrt{z/y}\, \epsilon^{-0.5\,j(\theta_r - \theta_g)} \tag{27}$$

from which

$$z_s = \sqrt{z/y} \tag{28}$$

and

$$\theta = 0.5\,(\theta_r - \theta_g) \tag{29}$$

It is proposed to call θ the *differential angle*, or the *distortion angle* of the line. It characterizes the difference between the imperfection angle θ_r due to the line resistance and the imperfection angle θ_g due to the leakage. When $\theta_r = \theta_g$, $\theta = 0$, and from eqs. (17) and (18) we get the familiar condition used in telephone engineering for a distortionless line: $r/L = g/C$.

It is sometimes convenient to express z_s in terms of x and b. Using eqs. (23) in eq. (28), we obtain

$$z_s = \sqrt{\frac{x\,\text{Cos}\,\theta_g}{b\,\text{Cos}\,\theta_r}} \tag{30}$$

Case of Zero Leakage. In most practical cases of power transmission lines it is permissible to put $g = 0$, unless the performance is desired in stormy weather, with poor insulation, excessive corona loss, or other abnormal conditions. When $g = 0$, θ_g is also equal to zero, and the foregoing expressions are somewhat simplified. The symbols which refer to this specific case are provided with the subscript zero. Eq. (25) gives

$$\tau_0 = 0.5\,\theta_r \tag{31}$$

and from eq. (29) $\theta_0 = 0.5\,\theta_r$ (32)

Consequently

$$\tau_0 = \theta_0 = 0.5\,\theta_r = 0.5\tan^{-1}(r/x) \tag{33}$$

The chart in Fig. 5 is constructed to represent this

relationship, and saves the time of looking up trigonometric tables. From eq. (24)

$$\beta_0 = \sqrt{(x\,b/\mathrm{Cos}\,2\,\tau_0} \times \mathrm{Cos}\,\tau_0 \quad (34)$$

and from eq. (30)

$$z_0 = \sqrt{\frac{(x/b)}{\mathrm{Cos}\,2\,\tau_0}} \quad (35)$$

The alinement chart in Fig. 6 gives values of β_0 and z_0 for known values of τ_0, $(x\,b)$, and (x/b), in accordance with eq. (34) and (35), and makes the actual use of these equations unnecessary. The scales are logarithmic so that a product is replaced by a sum. It would lead too far to explain here in detail the laying out of an alinement chart; it suffices to state that the chart in Fig. 6 takes the place of eqs. (34) and (35), and thus saves considerable time in obtaining the values of β_0 and z_0.[8]

Corrections for Small Leakage. Even under extreme conditions of transmission line operation, the uniformly distributed leakage is comparatively small, and the angle θ_g is not over 2 or 3 degrees. Therefore, the above described charts can still be used, and then small theoretical corrections applied to the values read off. For this purpose the angle θ_g must be computed from eq. (18). Comparing eqs. (25) and (31) we have

$$\tau = \tau_0 + 0.5\,\theta_g \quad (36)$$

Thus, to the value of τ_0 obtained from Fig. 5 for the case of no leakage, a small angle, $0.5\,\theta_g$, must be added to obtain the actual value of τ with the leakage. Similarly, comparing eqs. (29) and (32) we get

$$\theta = \theta_0 - 0.5\,\theta_g \quad (37)$$

We thus see that when leakage is present, the angles τ and θ are no more equal to each other.

In eq. (30) Cos θ_g can still be assumed to be equal to unity, so that with a small leakage $z_s = z_0$, and the expression (35) needs no correction. It must be noted that in this expression the angle τ_0 is used, and not τ. In other words, the value of z_0 obtained from Fig. 6 may be used with small leakage as well as without leakage.

In eq. (24) Cos θ_g may also be put equal to unity, thus giving

$$\beta = \sqrt{(x\,b)/\mathrm{Cos}\,2\,\tau_0} \times \mathrm{Cos}\,\tau \quad (38)$$

Comparing this expression with eq. (34), we get

$$\beta = \beta_0\,(\mathrm{Cos}\,\tau/\mathrm{Cos}\,\tau_0) \quad (39)$$

In other words, β_0 can be taken from Fig. 6 and the value so obtained corrected in the ratio of Cos τ to Cos τ_0.

* * * *

The writer's assistant, Mr. O. K. Marti, actually built the device shown in Fig. 1 and performed all the measurements described above. To him credit is also due for several mechanical details and for the drawings and charts used in this paper. The author wishes to express to him his sincere appreciation of the valuable assistance rendered. Mr. C. H. Dagnall, an instructor in Electrical Engineering in Cornell University, made a preliminary investigation of the possibilities of the proposed principle and performed some valuable computations and measurements. The author is under obligation to him for his active interest in this problem and for the use of some data from his thesis. Professor A. E. Wells, of Mechanic Arts, Mr. D. B. Green, Foreman of Machine Shop, and Mr. G. A. Culligan, Mechanician, all of the staff of the College of Engineering, gave generously of their time and skill in the making of the parts of the device, and it is only through their hearty cooperation that the device was completed within a comparatively short time.

8. For the theory of alinement charts see M. d'Ocagne, Calcul Graphique et Nomographie; T. B. Peddle, The Construction of Graphical Charts.

List of Symbols

b	capacitive susceptance, in mhos per mile
E	voltage vector at the point under consideration, in effective volts
E_2	same at the receiver end
f	frequency, in cycles per second
g	leakage conductance (leakance), in mhos per mile
I	current vector at the point under consideration, in effective amperes
I_2	same at the receiver end
$j =$	$\sqrt{-1}$
o	subscript meaning "no leakage"
r	effective resistance, in ohms per mile
s	distance from the receiver end to the point under consideration, in miles
V_a, V_b	component voltage vectors defined by eqs. (4) and (5), in effective volts
V_{ar}, V_{br}	same at the receiver end
x	inductive reactance, in ohms per mile
$Y = y\,\epsilon^{j\,(0.5\,\pi - \theta_g)}$	admittance of the line, in mhos per mile
$Z = z\,\epsilon^{j\,(0.5\,\pi - \theta_r)}$	impedance of the line, in ohms per mile
$Z_s = z_s\,\epsilon^{-j\theta} = \sqrt{Z/Y}$	surge impedance of the line, in ohms
$Z_0 = z_0\,\epsilon^{-j\theta_0}$	same without leakage
α	attenuation constant of the line, a numeric per mile
β	wave-length constant of the line, in radians per mile; in numerical applications and in Fig. 6, β is in degrees per 100 miles
β_0	same without leakage
ϵ	base of natural logarithms
θ	phase angle of the impedance Z_s, with the minus sign, or the differential angle of the line, in degrees or radians
θ_0	same without leakage
θ_g	leakage angle, in degrees or radians
θ_r	resistance angle, in degrees or radians
τ	imperfection angle of the line, in degrees or radians, defined by eq. (25).
τ_0	same without leakage

Electromagnetic Forces; A Search for More Rational Fundamentals; a Proposed Revision of the Laws

BY CARL HERING
Fellow, A. I. E. E.
Consulting Electrical Engineer, Philadelphia, Pa.

Reasons are given why it is desirable to revise some of our older laws regarding electromagnetic forces and motions which are the basis of all electromotive devices, in order to conform better to more modern developments. Researches with high-current densities in such mobile conductors as liquids and arcs, have brought out some heretofore unnoticed forces, the existence of some of which had been denied. Some of our older laws are claimed to mislead, to be inaccurate, incomplete, to involve unnecessary complications such as the forced definitions of a sliding contact, are based on the wrong fundamentals, specify results contrary to the facts, and are not universal, thereby checking possible progress if accepted as universal.

A new and simple general law is proposed, based on one of the fundamental universal laws of physics. It is shown how this might also be made the basis of a much desired universal law of induction. It leads to the existence of a force longitudinal to the conductor, which our older laws deny. Numerous experiments are described illustrating and bearing out the arguments. Suggestions are made showing how the laws and the present usual methods of mathematical treatment of such forces might be revised in order to make them more satisfactory, easier for the student to understand, and for the engineer to use. If the alleged improper restrictions imposed by former laws are removed, developments in new fields may become possible. In conclusion a tentative plan for revision is suggested.

THE foundations of a building erected some 50 or 100 years ago may have served their purpose perfectly, but when story after story is being added to that building reaching skyscraper heights a conscientious architect will do well to examine these foundations more carefully to find out whether they really rest on a firm rock bottom or whether they may not need some altering or strengthening to make them absolutely safe and trustworthy for the additional load.

Similarly, the fundamental laws of electromagnetic forces and motions formulated some 50 or 100 years ago may have served their purpose perfectly for a time, and some are still very serviceable if limited to special cases, but in the rapid development of the various applications of electricity more and more weight has been rested on these original laws and they are now being held responsible for applying equally correctly to new and much more severe conditions than were even thought of by those who framed them. The writer's experience with the application of electromagnetic forces in practise has convinced him that the time has come when they should be reexamined and tested, to find whether they can still safely stand the weight of the much greater responsibilities which we are now placing on them, or which may in the future be placed on them. As these forces are the basis of all motive devices using electrical energy it is of the utmost importance to the engineer to be able to place absolute reliance on them. Not only should the laws be so stated that he will not waste time and money trying to do what is really impossible, but it is quite as important, if not even more so, that they should not forbid what may be possible, as that may check progress in new, untrodden fields; if for instance a law is considered to be universal (that is, without exceptions) when as a fact it is not, it has improperly forbidden any developments in new fields in which there might have been progress. It is folly to violate nature's laws, but it should not be forgotten that our versions of them are man-made. Besides being absolutely correct these laws should also be as simple, and direct as possible; when we instruct people how best to go from New York to London we could, though should not, tell them to go via Japan and India; nor should the laws be burdened with complicated explanations necessitated by trying to make them fit apparent exceptions. Moreover it is our duty to the student and to the rising generation to give preference to that one of two otherwise equal forms of laws, statements or explanations, which is most easily grasped, understood and retained.

Purpose of this Paper

The purpose of the present paper is to show by means of experiments and arguments how certain of our older laws and explanations of electromagnetic forces and motions, as now taught in many text books and colleges, sometimes mislead or lead away from, rather than toward the truth, how they sometimes fail to apply, even specifying results directly contrary to the facts, and how they have practically forbidden us new fields in which progress might perhaps be made. Also to offer interpretations of these experiments and to suggest how the laws might be revised to bring them up to date, including a proposed new, simple, general law of the motions produced by these forces, which it seems to the writer applies correctly to all cases, old and new, and if so it is universal as far as we now know. Also to show how this new law may be made the logical basis of a new and general law of induction, which has the very great advantage of avoiding all the present complications due to the many involved and forced explanations of a sliding contact. In general the object of the proposed revision is to endeavor to simplify the whole subject for the benefit of the engineer and the student, to make the laws more reliable and more directly applicable; also to open up new fields, if any, which may have been

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forbidden to us before. The development of a revised mathematical treatment may thereby however become far more difficult, as the simple short cuts of Maxwell may then no longer be applicable.

The paper is intended merely to open up the subject and to make suggestions for a revision; it is not intended to be a completed and finished treatise on the subject. It is hoped some others with better facilities for research will find enough of interest and value in the experiments and in the suggestions to continue the investigations more thoroughly and perhaps to offer different and better interpretations and deductions from them.

If no unquestionable errors can be found in the proposed revision, the chief subject of discussion should be, whether the proposed revision would or would not have any advantages over the older system and this of course is a matter of opinion. It is of no consequence that it may be possible to explain some of the writer's experiments by means of the old laws, the important question is, which explanation is the more rational one and which is the better one for the student to grasp. The fact that the development of a corresponding mathematical treatment may then become far more difficult, ought not to be an insurmountable objection. Some of the points involved were recommended by Faraday and by Ampere, but they were discouraged by Maxwell; they did not fit in well with his mathematical short cuts.

The Physicist and the Engineer

It is the province of the physicist to discover and formulate the laws of nature concerning matter and energy and to develop the mathematical relations; and it is the province of the engineer to then take these laws and apply them to the benefit of mankind; the present subject therefore more properly belong under physics. During the past fifteen years the writer has repeatedly called the attention of physicists to the experimental evidence of the present unsatisfactory state, and showed how some of our laws have misled and even deceived the engineer when he tried to apply them; they were repeatedly appealed to by the writer to revise them so that the engineer could use them and depend on them as being correct. But not only was there no response (with one notable exception, the development of the quantitative relations by Northrup, concerning the "pinch effect," which has been of great value) but there was a surprising lack of interest in correcting alleged mistakes and shortcomings, and even a determined effort to prevent the publication of the writer's investigations. In one case publication was at first refused on the ground that if the experimental evidence was correct, which was easily demonstrated, it was so serious a matter to change one of the older laws, that it ought to be kept a secret! In another case the refusal was because it was, "so subversive of long established principles," the age of a law being considered more important than its correctness. Both papers however have been published.

The invention of a new and special definition of a sliding contact, to make an exception still fit an old law, seemed to be quite satisfactory to many physicists. Their attitude was that the older laws "were good enough for them." To make misfits fit, some have alleged that a circuit which was in fact open must be considered as being closed; others, that one which was in fact closed must be considered as being open. Their students have the sympathies of the writer, especially as one of the first things they learn in the laboratory is the sometimes very serious physical difference between an open and a closed circuit.

On account of this strange neglect, lack of interest, and even opposition of the physicist, which was not a credit to his profession, to provide the engineer with laws that are reliable and up to date, the writer must now appeal to the electrical engineers among whom there are some physicists of a more progressive class. The laws of physics are the engineer's most important tools; if their makers refuse to make proper tools for him he must make them himself.

Motions of Mobile Conductors

By passing currents, especially at high current densities, through such very mobile metallic conductors as mercury or molten metals in some types of electric furnaces, the writer many years ago noticed the existence of some heretofore unrecognized electromagnetic forces which tended to move the conductors, and being mobile liquids they responded much more readily to such forces than solid conductors do.

Some of these new forces were very formidable, for like most of such forces they presumably increase with the square of the current. The writer then made use of them in electric furnaces many of which are in daily use, these new forces being the absolutely essential factor, showing their industrial importance.

Arcs also respond readily to some of these forces.

Laws Need Revision

Not only were there these new forces, but that gospel faith in the reliability of laws which the engineer ought to be able to have, led the writer in two notable cases to waste time and money before finding out that the laws had not been correctly stated. These experiences gave rise to the present investigation which developed similar results with other laws.

It will be shown below how some of the older laws sometimes mislead, leading us away from rather than toward the true goal; others apply ambiguously, or even specify results quite the contrary to the facts. Some supposedly universal ones (that is, having no exceptions) were found not to be so, thereby having checked possible progress. Some were not based on their true fundamentals but on mere incidental factors; some which apply correctly to special cases have been applied to the more general case, which process may lead to serious errors. In a mathematical treatment it is important to select the best fundamental, which has

not always been done; thus if the mathematics of something circular, like a soap bubble film, is based on the radial pressure, the formula fails for the tension of a plane film, giving infinity, which is not true; while if based on the tension of a plane film the internal pressure in a bubble may be determined from it. Our unit of current is based on the magnetic force of a circular circuit. A closed finite line had better be made a special case of an infinite straight line, than the reverse.

In going from the general to a special case some factors generally drop out and can never again reappear in any subsequent deductions from the mathematical treatment of this special case. Or if a mathematical treatment is started for a case which is really a special and not the fundamental one, it is an error to apply it to the more fundamental one, or to other special cases in which the dropped factors may be different. Yet it seems such mistakes have been made. In a complicated system it is therefore important to find or select the best and most basic fundamentals.

A revision of our former laws is also desirable now that it is known that every electric current is merely a movement of electrons in the conductor. In Fig. 1, if negative electrons pass from one body A to another

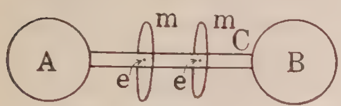

Fig. 1

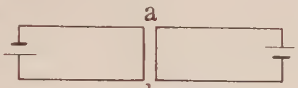

Fig. 2

B, through a conductor C, what we call a current flows through that conductor during that passage, creating simultaneous magnetic effects m, m, around it, each caused by its moving electron e, e; after the operation the body A is left charged positively and B negatively. Telegraph messages have been sent by currents in such a conductor, after an aurora borealis. It is therefore no longer an absolute necessity to consider every electric circuit as being a "complete circuit;" in many cases it is a great convenience to do so, a short cut, but in some it misleads and involves great difficulties to make it fit the facts; a law to be universal should therefore not be based on the circuit being a complete one. The complete circuit should better be made a special case of a unit length of a straight circuit. Ampere advocated basing the mathematical treatment on elemental parts of circuits, but Maxwell did not approve it, preferring the easier method or short cut based on the complete circuit, which however is a special case and not the most general one.

When two current carrying conductors are in some parts quite near to each other as at $a\ b$ Fig. 2, and at other parts far apart, the force between them will reside almost entirely in the near parts $a\ b$; in practise this force would be practically the same whether the rest of the circuits are a foot or a mile long. In engineering work the consideration of the "rest of the circuit" is generally quite unnecessary; the leads to a motor do not electromagnetically affect the mechanical forces in the motor.

The present tendency to abandon that useful stepping stone, the ether, also makes it desirable to revise some of our former conceptions. A magnetic field in space was thought to be a storage of energy in the form of a sort of stress or strain in the surrounding ether, which was and is still a very convenient and useful picturization. It seems to be much better, however, to consider the magnetic field around a current-carrying conductor to be merely an action at a distance, as Faraday proposed, the seat and source of the force being in the material of the conductor and not in the space around it; no assumption of any ether is then necessary. The reaction of these external forces on each other or on a foreign force, must then manifest itself in the material of the conductor through which the electrons are passing, and at the places where these forces are originated by them.

It is therefore the conductor itself, that is, the matter in it, which had better be referred to in these laws and not the more subtle currents, circuits, fields or ether. Experiments illustrating this will be described below.

It is also our duty to the student and the rising generation to point out any errors and exceptions and to revise the laws, conceptions and explanations so as to make them the simplest and clearest possible in order that they may be grasped and retained as easily as possible. Complicated conceptions and explanations such as many of those for sliding contacts, are objectionable. Above all, the laws should be strictly correct, should not mislead and should if possible be universal.

Mistakes in Some Laws

The elementary law given in every text book, that like currents attract and unlike repel, is wrongly worded; it is not on the currents but on the material of the conductor that these forces act. If they acted on the currents then the current density would have to be greater in the center of a conductor than near the outside, and Ohm's law would no longer apply to large conductors; or when two conductors are close to each other the current densities in different halves of the same conductor would have to be different; or the current in the middle of a cathode or anode in an electrolytic bath would have to be greater than elsewhere. But we know these are not the facts. Moreover like cathode rays repel. The industrially important pinch effect[1] would not exist, yet we know it does. Maxwell (Art. 501) recognized and called attention to this important distinction between the current and the conductor, but many of his followers did not. Nor did Maxwell continue to make a similar

1. Considering a conductor as consisting of a bundle of filamentary ones, this force tends to make them move to the center. When the conductor is a liquid the material is free to move and these radial forces may then become great enough to cause rupture. This phenomenon has been called the pinch effect. See bibliography at end of this paper.

distinction in his law of induction (Art. 531) as he ought to have done.

In a paper before this Institute (TRANS. Vol. 27, Part 2, 1908 p. 1341) the writer described a simple experiment showing conclusively that a similar distinction must also be made in Maxwell's law of induction. It is the conductor, that is, the matter and not merely the circuit, which must cut the magnetic flux in order to induce a current; if the circuit alone cuts it, the conductor remaining stationary with respect to the flux, there will not be the slightest induction even though exactly the same linkages of the flux and the circuit have taken place. (See also a modification of Faraday's experiment in the *Jour. Frank. Inst.* Nov. 1, 1921 p. 605). This important law therefore also requires revision. It moreover also fails to show in what part of the circuit the induction actually takes place and therefore what parts are dead or inactive, which is sometimes of importance to know.

The writer maintains that just as in the two cases mentioned above, it is necessary to make a similar distinction between the conductor itself and the magnetic field surrounding it. The forces in this field have their seat and origin in the material of the conductor where the electrons are passing through it; which should therefore be their anchorage or abutment; any actions of these forces on each other or on a foreign force should, therefore, have their reaction in the conductor. If a large heavenly body passed through the field of force of gravity between this earth and the sun, the abutments of the new gravity forces would be in the earth and the sun, not in the space between them. It is difficult to conceive how the abutment of an electromagnetic force could be in the ether; the energy in the cases here referred to is not a radiated wave motion.

In other words the flux around a conductor or magnet should be pictured as though it were in some way elastically attached to the material in which its source lies. Faraday entertained this idea (*Exp. Res.*, Vol, 2; p. 293; Vol. 3; p. 447), as pointed out by Maxwell (Art. 529) when the latter says: "He even speaks of lines of force belonging to a body as in some sense part of itself, so that in its action on distant bodies it cannot be said to act where it is not." Maxwell however does not favor the idea of action at a distance (Art. 552).

A distinction should here be made between a field of force or a storage of energy, which remains with the source, such as in most electromagnetic machinery, and one which leaves it completely as by radiation, such as in wireless transmission. In the latter case the forces acting in such fields of energy do not react on the source; when a bullet hits a target or is deflected, the forces on it do not react on the gun. The present discussion refers only to fields of force or energy which remain with their source.

One of the most common of the older laws concerning the production of motions by a circuit is to the effect that a circuit will produce such motions as will make it include more flux; Maxwell (Art. 489 and 490) states it in equivalent terms. It will be shown below that this law, though often true, is not based on the correct fundamental principle, the increase in flux so often noticed being an incidental and indefinite secondary consequence which may or may not take place, and is not the true primary cause, and therefore not the proper crucial factor in a law. In the most usual case of a motor, the flux does not increase but remains constant, hence the law fails even in the most usual case; complicated and involved definitions of sliding contacts must be called to the rescue; the Faraday unipolar motor eliminates the element of commutation. But more than that, in the simplest and most fundamental case, which is described below, (the proof of which is given in the Appendix) the flux is actually *less* in amount after the motion.

This law has led many to draw wrong conclusions, as was illustrated by the writer receiving from many physicists a positive answer to a certain case which was directly contrary to the facts. Moreover it is the flux energy and not the flux which is concerned when a circuit does work in producing motion; the flux energy may increase or diminish while the flux can remain constant.

Another favorite law is that only such motions will take place as will increase the self inductance. This is a badly defined law as it involves a factor which is entirely foreign to the case, the number of turns in a coil; the magnetic forces are entirely independent of this factor, at least for direct currents; they depend on the ampere-turns. The self inductance is a purely geometric quantity and is independent of any current or energy. In every motor, and in certain electric furnaces in which powerful motion exists, the self inductance remains constant, as also in the experiment Fig. 17 described below. In the one described in Fig. 16 it will be generally admitted that it actually is *less* after the self produced motion. Another case in which it is less after the motion is referred to in the Appendix. It may be claimed that these cases are unusual ones; but a law to be depended upon as being really universal must not have a single exception. The magnetic energy stored in a coil depends only on the ampere-turns, the reluctance and the flux, it is entirely independent of the self inductance in the sense that the latter may be greater or less in different cases in which the former are the same. The fact that this energy is readily calculated from the self inductance of any particular coil and the current, misleads one to believe it to be a crucial factor in matters concerning energy, but it is not, as the energy is dependent on the ampere-turns but not on the turns by themselves.

Another law is to the effect that anything that increases the stored energy will give rise to a force. There is no such increase in a running motor; and in the most fundamental case described below the stored energy becomes *less* (as it should) when the force acts.

Another is that such motions will take place as will

increase the permeance. This also fails for motors unless rescued by forced definitions of sliding contacts. A noted physicist recently explained to the writer that in a certain experiment the motion was due to an "increased reluctance" the exact reverse of an increase in permeance.

With such ambiguities and inaccuracies of the older laws, a new law seems very desirable. Above all a law should not forbid what may be possible.

A General Law of Motions

In view of these descrepancies, and the fact that when forces act to produce motion it involves energy, the writer concluded to look for a general, universal law among those for energy.

There is a well recognized general law in physics applied generally to a system of mechanical forces and energy, to the effect that *in any system such motions will tend to take place as will reduce the potential energy of the system*; this potential energy is thereby transformed into the kinetic energy of the motion; water flowing from an elevated storage reservoir is a simple example.

It is believed that this is a universal law of nature and therefore should apply in quite as general a way to any and all electromagnetic systems in which potential energies are involved and mechanical motions are produced. To make it more convenient to be applied directly to electromagnetic systems, it seems preferable to redraft it and state it in such electrical terms that it will not only be correct and easily understood but that it cannot be misunderstood, nor will deny what may be possible. What the best wording is, is a matter of opinion.

The writer suggests the following version for the usual conditions: *in an electromagnetic system in which the current is being maintained by a source, any and only such mechanical motions of the conductor will tend to take place as will generate a counter e. m. f. somewhere in the circuit.* The actual motions which this tendency will produce will depend, of course, on the particular freedom of motion which the various parts of the circuit may have. The counter e. m. f. is not necessarily generated in the part that moves as will be shown below. It is believed that this is a universal law of all such electromagnetic systems, that is, that there are no exceptions.

The reason for introducing the clause about the current and the source is to exclude certain very unusual cases, like condenser discharges, and others in which there is (as with permanent magnets) no outside source of supply of additional energy when some is withdrawn from the system; to also include such unusual cases the statement of the law would seem to have to suffer in simplicity. The universality of the law is, of course, claimed only for the cases specified in it, which however are the usual ones.

Magnetic material such as iron in such a system can store and give off some energy and thereby may introduce a correction factor in some cases. General laws are supposed to be exactly correct only under theoretically perfect condition, and just as the element of friction does not invalidate the general laws of mechanics, so the presence of iron should not be considered as invalidating this law.

It will be noticed that, as in the general law, there are no further restrictions as to any particular directions of the forces which cause these motions; nor are there any apparent reasons why there should be; according to this version of it any and all motions whatsoever are therefore justified, no matter what the direction of the forces may be which cause them.

The chief reason for proposing this electrical version of the general law is that it is believed to be without exception and in fact a necessary consequence, that when any current-carrying system which is connected to a source produces mechanical motions of any kind, that is, gives off energy, there is always produced a counter e. m. f., which when multiplied by the current (in phase) is the quantitative equivalent of the mechanical energy produced. This alone might justify this version, but there are further reasons and explanations.

The Counter E. M. F.

In a system consisting of current-carrying conductors, it will doubtless be conceded that at least in the sense of this general law, the potential energy in an electromagnetic system resides in the magnetic flux energy which is stored when the current was started and is somewhat like that of inertia. It will probably also be conceded that any self-produced mechanical forces which tend to produce motions, are the direct results of the action of the energy stored in this flux, which may for this purpose be considered as a sort of stress or strain or inertia; the greater this flux energy the greater the forces are likely to be. It is believed to be true also that when such flux energy actually produces mechanical motion, that is, kinetic energy, it disappears as such, just as when a mechanical stress of strain relieves itself by producing motion it disappears as such; but such a disappearance is quite different in kind from that occurring when a current-carrying circuit is broken, as the potential energy of the flux in the latter case is transformed into energy in the form of the momentary current caused by the direct e. m. f. which the disappearing flux produces; the e. m. f. then is a direct and not a counter one.

When the potential energy of the flux is transformed into the kinetic energy of mechanical motion, it seems evident that no counter e. m. f. should be produced directly thereby, though there will be when this lost energy is subsequently replaced again by the current. This is shown by the following example of a more fundamental case.

Assume two parallel copper rings at 0 deg. absolute temperature at which their resistance is zero; let like

and equal currents be started in both by drawing a magnet pole through them; the energy of this process will then be stored as magnetic energy and the currents which maintain it would then continue to flow indefinitely. Now let the rings move toward each other by their attraction over a certain distance and then stop, thereby converting part of their potential energy into kinetic; there will then be less magnetic energy and therefore less current flowing after the motion has ceased; this cannot be due to a counter e. m. f. as the motion has ceased.

If two unlike poles of two permanent magnets are permitted to move toward each other, an amount of the flux energy must have disappeared exactly equal in amount to the kinetic energy produced by this motion; this is restored again when the two poles are subsequently forced apart.

In both of these cases the flux itself as distinguished from the flux energy, will also be found to be less, the proofs of which by Prof. R. E. Brown are given in the Appendix.

These two illustrations were chosen because there is no source of new energy connected to them to replace that which was transformed into mechanical energy. They are therefore more basic or more fundamental than the usual cases, as showing what actually takes place physically in the simplest case, and the order in which things take place; they both show that when the potential energy of the flux is converted into the kinetic energy of motion the flux energy (and in fact the flux also) disappears as such, and in the former case without generating any counter e. m. f.; the process here is not masked by any addition of energy from an outside source. The immediate, practically simultaneous, replacing of this lost flux energy by the usual source is therefore hereby shown to be a secondary consequence, and not the primary cause of the motion, and it is this supply of new energy which really generates the counter e. m. f., just as in the starting or increase of a current. This seems to be an explanation of the reasons why a counter e. m. f. is always generated when such a system generates mechanical motions.

Concerning the above proposed experiment with the two rings at absolute zero (the result of which can be definitely calculated, as shown in the Appendix, easier than it could be measured), it has been variously claimed by some that with zero resistance it is not possible to induce any current at all, and by others that even with the slightest induced e. m. f. the current would then be infinite; these are rather large differences of opinions. The facts are that at nearly 0 deg. Onnes induced a finite and limited current which persisted for a long time. For the purpose of the above argument it may be assumed that the conditions are like those in the Onnes experiment, therefore possible, and that the current was not decreased appreciably by the very small resistance, during the very short time of the motion.

That the current would not be infinite at absolute zero resistance nor enormous near to zero, is shown by the fact that the finite amount of energy spent in drawing the pole through the rings, is stored in the system as magnetic energy of an exactly equal amount; it could not possibly be any greater. Hence the current which would flow continuously is only that which by its ampere-turns and with the existing reluctance, would produce and maintain exactly that amount of flux energy. It is analogous to the energy of inertia stored in a spinning top, under frictionless conditions.

The Potential Energy

One of the objections to using the term "potential energy" in the above electrical equivalent of the general physical law, is that it may not always be clearly and definitely understood. But a greater objection is that it may sometimes involve necessary and perhaps complicated explanations of apparent contradictions and ambiguities; the diminution and disappearance of the potential energy (the energy in the flux) is not always as readily apparent as it is in mechanics; especially as the process is generally masked by an immediate replacement of this energy by the source; in a motor the ultimate quantity of the flux energy remains constant; in some cases it is even greater after the motion than before. There is a generally accepted law (though as shown above it is not always correct) that a circuit always tends to move so as to embrace the largest possible amount of flux, therefore apparently directly contradicting this general law; the amount of the flux and of the flux energy however, by no means necessarily vary in the same ratio, the energy is the product, of the flux and the m. m. f.

A careful and unbiased analysis will, however, show that these contradictions and anomalies are only apparent and not real; it can be shown that any additional or new flux energy has in those cases been added by the source of current after the motion has taken place or while it is taking place; the motion itself may have made room for more flux or have decreased the reluctance. This increase of flux energy is a secondary result and not the primary cause of the motion, as seems to have been claimed; it may or may not take place. Similar anomalies and apparent contradictions occur in the application of the more general law to purely mechanical conditions, yet they do not in fact violate that law; for instance, the potential energy in the water in an elevated tank which is being kept full by a pump, will according to the general law, cause it to flow into and fill another neighboring tank and at the end of the operation there will be more potential energy than there was at the start. To avoid such anomalies and apparent contradictions it seems preferable to use a different term than potential energy in the electrical equivalent of this general law.

Maxwell (Art. 568) defines potential energy as a tendency to a change of relative position, and he some-

times treats the energy of magnetization as potential. He says furthermore (Art. 638) that he "assumed that the energy of a magnetic system is potential energy, and that this energy is *diminished* when the parts of the system yield to the magnetic forces which act on them." (The Italics are his).

To the writer it therefore seems that the generation of a counter e. m. f. is the best crucial condition in the electrical equivalent of that general physical law, to take the place of the reduction of the potential energy. That they are the equivalents of each other, or at least necessary accompaniments of each other, when there is a source, seems evident; the general physical law calls for such motions as will reduce the potential energy, the flux energy in the electrical case; this flux energy then must disappear as such when it is transformed into the kinetic energy of motion; as the current necessarily always generates as much flux as the reluctance of the surrounding space permits, it will at once replace any flux which has thus disappeared and, as is well known, the generation of any flux in a circuit is always accompanied by a counter e. m. f. The writer has applied this simple law to every case he could think of, old and new, and it never fails to apply correctly. If no exceptions can be found to it then it seems to be a universal law for the class of phenomena specified in it.

The Hall effect, like the skin effect, seems to deal with the shifting of the current paths in a conductor, as distinguished from a movement of the conductor itself. They therefore would have no direct bearing on this law except in so far as the changes of current paths may change the flux distribution which in turn may affect the forces.

Deductions From This Law

If this law is sustained, a number of deductions follow. It specifies no limitations to any particular directions of the forces which produce the motions, hence any directions are possible, provided only that the motion generates a counter e. m. f. somewhere in the circuit. It has been strenuously maintained that these forces could be only perpendicular to the conductor and never otherwise; it therefore opens up a formerly forbidden field. If for instance any particular motion is desired, it follows from this law that if that motion is such as would produce a counter e. m. f. then it ought to be possible to make the system produce it by providing the necessary freedom of motion; this has for instance been made good use of for giving molten metals a desired motion in some types of electrical furnaces.

Lengthening a current-carrying conductor (the stretch effect), reducing its cross section (the pinch effect), straightening it (the corner effect), winding it into a coil, etc., all produce a counter e. m. f. in a constant-current circuit and the circuit could therefore (theoretically at least) be made to produce them. According to Lenz' Law reversing any of these motions should generate current. Some of these deductions are further discussed below.

Longitudinal Force

One of the deductions from this law is of special interest because it has been most hotly contested; there is however also another proof of this deduction which is entirely independent of this law (and therefore aids in confirming the law) as will be shown in connection with Fig. 9. If a current-carrying conductor be lengthened (as for instance by stretching, sliding contacts, mercury troughs, etc.) new flux will be produced around the added part and the production of this will generate a counter e. m. f., as in any conductor in which a current is started. Hence it would follow from this law that the circuit itself could produce such a lengthening if the necessary freedom of motion exists. In other words, a current tends to stretch or lengthen its conductor, or more generally, there are longitudinal forces tending to move the conductor in the direction of its axis.

This force, the existence of which can readily be shown experimentally as described below, the writer years ago colloquially termed the "stretch effect," it being a complementary phenomenon to the "pinch effect" which tends to crush the conductor radially, both seem to follow the same laws and lead to the same ultimate result in liquid conductors by rupturing them, when strong enough.

This longitudinal force is also a consequence of conceiving that these electromagnetic forces have their real origin and abutments in the material of the conductor at the seat of the moving electron which causes them; that is, the forces in the field around a conductor are actions at a distance (as Faraday maintained). In Fig. 1 the lines *m m* represent the disks of flux around those parts of a conductor; such like lines of force are known to repel each other, and if the seats or abutments of these repelling forces are in the material of the conductor where the electrons *e*, *e*, which produce these lines are moving, the conductor will tend to stretch. The greater the density of this self repelling flux the greater this force.

Physicists have emphatically denied and many of them do so still, that such a longitudinal force exists or could exist.[2] Maxwell (Art. 507) described an experiment, due to Ampere, made under certain conditions, from which he generalized that no such force existed or could exist; the writer admits that it would not make its appearance under the conditions in that particular test, (in which the two longitudinal forces are equal and opposite), but that under different conditions to be described below, (Figs. 3 to 11), this force becomes very evident. Recognizing both forces means that a resultant in *any* direction is then possible.

This longitudinal force does not appear in the usual mathematical treatments of electromagnetic forces; the reason seems to be that such treatments were originally

2. Northrup's Laws of Physical Science (1917), p. 152, par. 3. "If a wire carries a current no external magnetic force can so act upon the wire as to tend to make it move in the direction of its length."

based on a special case in which this longitudinal component consists of two opposite forces which are exactly equal and therefore drop out of the mathematics; having once dropped out this force can of course never again reappear in any subsequent mathematical deductions which are based on this original case even when they are unequal, as they are in some of the experiments described below.

These two new forces, the pinch effect and the stretch effect, are generally not great enough to crush or stretch solid conductors, (though they might perhaps act on the softened filaments of forced incandescent lamps), but with liquid or gaseous conductors like those in some electric furnaces or in the arc, they may become of vital importance, being sometimes quite formidable, and should therefore be recognized, studied, and included in mathematical treatments; to deny their existence might check possible progress and developments. That they are of practical importance is shown by the fact that hundreds of electrical furnaces are at present in daily successful use in which this longitudinal movement of the liquid conductor by its own current, is the absolutely essential factor.

Some physicists who declined to recognize this longitudinal force have endeavored to explain the very evident longitudinal movement in the writer's earlier experiments with liquids, as a hydrodynamic action of the liquid due to the pinch effect. But as some of the experiments described below show that this force will also move solid conductors lengthwise, they are a positive proof that the action cannot be primarily hydrodynamic in the liquid; in the writer's opinion the hydrodynamic action resides in the field itself.

Unlike the stretching of a compressed helical spring, this stretching theoretically continues indefinitely and is constant if the current and the cross section of the conductor remain constant, as in a mercury trough. As in all these phenomena, it will no doubt be found to increase as the square of the current. It is independent of the direction of the current or the length of the conductor. For the same current it becomes greater the smaller the cross section and can rupture the circuit by tearing it. It no doubt is greatest at the center of a round conductor and is least at the circumference. In a liquid conductor the motion is therefore greater along the central axis than near the circumference. Like a compressed helical spring a flexible circuit secured only at the two ends may form itself into the shape of the letter *C* as is often seen in the arc, or even like the letter *S*, if thereby it can lengthen itself (see Fig. 8). It has been suggested by a noted physicist that this might explain the sinuous character of a bolt of lightning.

A circuit making an angle at a hinged joint tends to straighten itself, due to this stretching force. This is usually explained by the action of the component of a force perpendicular to the moving part, and when it is straight this force which straightened it becomes zero. It can be shown however, that if the necessary freedom of motion exists at the joint the force which straightened it, namely the repulsion of the disks of flux, still continues and will then stretch it, showing the older explanations to have been wrong. A flexible circuit is known to expand; why should this same force cease when the conductor becomes a straight line; it does not; our former limitation to a perpendicular force has misled us. A straight soap bubble film (therefore having no radial pressure) has a tension just as the curved one has.

A straight conductor leading down into a large liquid conductor tends to be moved upward out of the liquid, if the proper freedom of motion exists, and new flux will appear around the lengthened part, causing the counter e. m. f. In general, where there exists any difference of flux density near a conductor there will be a tendency to produce a motion to equalize this flux density if that motion would generate a counter e. m. f. In experiments care must of course be taken that the force is not counterbalanced by an equal and opposite force somewhere else, which is generally the case. As will be shown below, the longitudinal force may be made very evident by making the two opposing forces unequal.

Ampere had referred to such a possible longitudinal force and gave some formulas; this is briefly discussed by Maxwell (Art. 526) and is not then denied by him, though he denies it elsewhere. In Art. 687 however he described the Ampere trough experiment (see Fig. 5) saying "This experiment is sometimes adduced to prove that two elements in the same straight line repel one another" (this is what the present writer calls the stretch effect) "and thus to show that Ampere's formula, which indicates such a repulsion of collinear elements, is more correct than that of Grassman, which gives no action between two elements in the same straight line." Maxwell adds that the experiment does not favor one more than the other; it is significant that he here does not deny such longitudinal forces, though he does elsewhere.

According to Maxwell (Art. 527) Ampere had claimed that the force between two elements of the circuit, (evidently meaning limited parts of a circuit, or of circuits), is along the line joining them, which Maxwell (Art. 527) considers the best assumption. For conductors inclined to each other, such lines joining their parts must necessarily be inclined to them, hence such forces *must* have longitudinal components. (See Fig. 9).

The Corner Effect

Many years ago the writer noticed that in a wide mercury trough which turned a right angled corner, there was great agitation of the mercury at that corner when a large current flowed, showing the presence of decided local forces; the current was not great enough to show a marked pinch effect in the straight parts; he called it the "corner effect." The writer's explanation was that as the amount of flux must of course be the same on the inside and outside of the corner, the density must be far greater on the inside part of the corner,

therefore the forces on the mercury there must be far greater than those on the outside part, hence the agitation.

Recognizing the existence of the longitudinal force, this experiment can also be described as the mutual action of two currents whose conductors are inclined toward each other (see Fig. 9); the forces will of course be greatest where they are nearest to each other, in this case at the corner. When these two currents are unlike in direction (as in the above case) there should be a longitudinal flow of the conductor away from the corner, and for like currents toward the corner. An electric furnace based on this, for obtaining a unidirectional flow of the liquid conductor, operated as predicted, the motion being quite strong and rapid (*Jour. Frank. Inst.* Nov. 1921, Fig. 9 and p. 612).

Quantitative Value of the Pinch Effect

In the c. g. s. system the writer found (*Met. & Chem. Eng.* Vol. 9, Feb. 1911, p. 86) that the quantitative value of the pinch effect at the central axis of a circular conductor was $P = I^2/S$ in which P is the pressure in dynes per square centimeter, I the current in c. g. s. units, and S the cross section in square centimeters. This pressure is of course greatest at the center and least at the circumference. The fact that this is a unit relation in the c. g. s. system is of interest. It will be seen that the pressure is not proportional to the current density. As the current in a given liquid conductor is increased, an unstable state is ultimately reached at which this force increases automatically by contracting the conductor enough to rupture the circuit.

Hydrodynamic Action in a Magnetic Field

No one has yet deduced the quantitative formula for the longitudinal force, this force having dropped out of our present mathematical treatment of such forces. But the writer has reasons to believe it will ultimately be shown that these electromagnetic forces in a magnetic field act as though the medium, the ether, were like a liquid or gas, that is, they act hydrodynamically and therefore can turn corners, as it were. As they act on solid conductors also, the conductor itself need not be this hydraulic medium, as was formerly claimed by others.

If this is true, the quantitative formula for the stretching should be exactly the same as that for the pinch effect. Some years ago Northrup made a very careful and accurate measurement of what he claimed was the pinch effect, but as the force he measured was a longitudinal one (claiming that the liquid conductor, mercury, acted, as the hydraulic medium) the writer maintains that what he really measured was this stretching force. His measurements confirmed the formula of the pinch effect, hence the writer's conclusion that they are numerically equal. Maxwell (Art. 109) in discussing so-called static electricity says "the numerical magnitude of the pressure" (between lines of force of static electricity) "being equal to that of the tension" (along these lines) "and both varying as the square of the resultant force at the point." Many parallels between electrostatic and electrodynamic phenomena exist.

If these forces act as though the medium (not necessarily the conductor) were a fluid, the whole subject is simplified as only one of the two magnetic forces need then be recognized as the primary, either and preferably the tension along a line of force, the other, the repulsion of like lines, being a hydrodynamic resultant, just as the radial pressure on the side of a cylindrical pump is produced by and is exactly equal to the longitudinal pressure of the piston.

Pole Moving Along a Line

A third electromagnetic force is sometimes included with these two, namely the force which tends to move a single pole along a line of force; Faraday showed this in a very ingenious experiment (see Fig. 12). This force is however not a property of the field itself, but of a foreign body which is introduced into it, that is, the force is that between two independent fields.

There is a deduction from this experiment which seems to bear out one of the writer's contentions. It will be conceded that when a single pole moves along a line of force encircling a conductor, the equal and opposite reaction required by Newton's third law should tend to rotate the conductor around its axis in the opposite direction, which it does, as will be shown below. As there is no physical connection between the pole and the conductor it seems that the flux around a conductor must be considered as though mechanically connected with its conductor, or in other words that it is a case of action at a distance from the moving electron.

The "Sliding Contact"

The most unsatisfactory and most confusing element in our present system, and the most troublesome and discouraging one to the student, is the inevitable "sliding contact." Every book-writer and teacher seems to try to invent a new definition.[3] When new

3. As a good illustration the following is from a letter recently received from a professor of physics in a well known college, who is responsible for teaching many young men. "I think the only satisfactory way to treat such cases, and the way in which they usually have been tacitly reasoned out, is to imagine the sliding contact replaced by a very thin layer of conducting liquid in which the motion varies continuously from one surface of the layer to the other. Then everything becomes clear (!). . . Sliding contacts are to be treated as the limiting cases of a thin transition layer in which the motion varies continuously from one side of the layer to the other." He speaks of "what happens to the flux-linkage when the filament is broken by the sliding at a sliding contact. . . If you do not like my conducting fluid (in the above definition), then put in a short wire across the break and consider what happens during the thousandths of a second before the wire breaks." The circuit was never broken in the case referred to.

A well-known electrical engineer and able physicist defined a sliding contact as a "commutator with an infinite number of sections." Maxwell (Art. 491) says that in the case of a sliding contact the circuit "must be regarded as a system of two or of some greater number of circuits of variable strength," currents of even opposite directions.

experiments conflict with the older laws, a new definition is at once invented to try to make them fit, and this seems to be quite satisfactory to many physicists. To the writer however the responsibility placed on the sliding contact has always appeared as a tacit admission that something is wrong, an admission of our ignorance or of some mistake.

All this could be avoided by the revision suggested below. The adequate definition of a sliding contact then reduces itself as it should, merely to "a contact which slides," and nothing more.

General Law of Induction

Our laws of induction (Faraday's law of cutting lines of force and Maxwell's law of change of linkages in a complete circuit) were based on special cases. They have been invaluable and perfectly satisfactory when limited to those special cases. But trouble and misfits generally arise when the laws for one special case are applied to another special case; it is unwise to attempt it. Moreover as both are special cases can we depend upon it that together they cover all possible cases, without exception, that is, are they universal.[4] Has not our belief that they are universal perhaps checked development in other special cases. A single pole will move around a conductor, hence the reverse motion should generate a current. A magnet will rotate a conductor (Fig. 14) hence rotating the conductor near a magnet should generate a current. Contracting a current-carrying conductor, or expanding its cross section, or unwinding it from a coil, and perhaps many other odd motions, ought to generate current. Some of these cases of induction are difficult to explain by our present laws, except perhaps by means of special forced and involved definitions of a sliding contact. Our older laws would surely not have led us to them, though no claim is made here that those above mentioned are of any industrial importance.

The writer maintains that this state of affairs is not satisfactory and that we ought to look for a more fundamental general law of induction, of which the present ones are then special cases, to which they should then be limited. Such a general and presumably universal law could be based on a combination of the new law given above for motions and Lenz' law, that is, if any of these self produced motions are reversed, there will be induction. Lenz' law has presumably never been questioned, and the law of motion is nothing more than an electrical version of a well established and non-contested law of physics concerning energy; both are believed to be universal. In such devices as transformers the relativity principle is then also involved, in that it is immaterial whether the conductor moves across the flux or the flux (originating with the moving electron) moves across the conductor; there is relative motion in either case.

4. That Maxwell considered his law to be universal is indicated in Art. 541 in which he says we can "enunciate completely the true law of magneto-electric induction" in this way.

Intensity and Direction of Field not Specific Enough

It has been claimed that a magnetic field is completely specified by its intensity and direction. This means that if the source, either a magnet or a current-carrying conductor, moves in such a way that the field at any outside point does not alter its intensity or direction, then the field does not move, in the sense that it would not cause induction in a fixed conductor. Experiments seem to indicate that each line is attached to its source, the conductor, as the rim of a wheel is attached to its hub, except that the attachment is elastic. If so, the above definition of a field is incomplete and should include a reference to the motion of the source, even if such motion does not alter the intensity or direction at any specific point. See also Figs. 15 and 17.

Present Mathematical Treatment Needs Revision

Our usual mathematical treatment has misled us in creating a very positive and nearly universally accepted belief that the only force which can possibly exist is one perpendicular to the conductor, like the one in the definition of the unit of current. This has checked progress. The usual mathematical treatment should not have been based on a special case in which the longitudinal force happens to fall out in the mathematics.

A new mathematical treatment should now be devised in which the longitudinal force is recognized. The mathematical short cut based on integrating around the "complete circuit" which often involves quite unnecessary complications, should be limited to those many cases in which it is useful. It should be accompanied by a mathematical treatment (far more difficult to devise) based on limited parts or elements of circuits (as proposed by Ampere) and on their relative inclination and distance apart. When a desired force is like that between two inclined conductors, by far the greatest part is where they are nearest together, and we should therefore be able to determine how long it is economical to make such conductors.

It is believed that such a system could be based on the assumption of only a single magnetic force, the tension along a line of force; then deduce the other, the repulsion of like lines, on the basis that there is an action analogous to that in hydrodynamics and that therefore this one force can produce motions in *any* other direction depending only on the freedom of motion which exists. It should also be based on the forces being actions at a distance, the abutments of these forces being in the material of the conductors and in that part in which the corresponding electron is moving.

Experiments

The following experiments, mostly original with the writer, illustrate some of the facts, opinions and departures expressed above. The results in many of them were in accordance with the predictions based on

these opinions and contrary to opinions based on the older laws. Gospel faith in the older laws would not have led to them. Some of them have been published before and are reproduced here (by request) to illustrate the deductions from them. Many of them have been discussed for some time with able physicists whose comments have been considered, though generally when they could not justify them with the older laws they ignored the experiments.

The apparatus was mostly crude and improvised though the results were always quite definite and decided. No claim is made that this is a thorough and completed research, nor were any quantitative measurements made. The experiments should be considered merely as a preliminary investigation.

As it is often not possible to multiply these forces by using coils of many turns, the currents required are generally rather large and cannot be kept flowing long on account of the heat. About six storage batteries of the usual portable laboratory type, and a low volt transformer giving up to about 2000 amperes, were generally used; in some cases a dry cell current suffices.

In Fig. 3, *W* is a long horizontal wire suspended so that it can move lengthwise. One end dips into the center of a large dish of mercury *O*, in which, therefore, there was practically no change in the flux when the wire moved slightly. The other end dips into the narrow mercury trough *M*, in which a force to stretch or lengthen that electrically elastic part of the conductor could manifest itself. When current was passed the wire moved decidedly to the right showing the tendency of the part *M* to stretch. Assuming a constant current, new flux was produced in the part which was added to the mercury trough part of the circuit by this lengthening; and it is in this part that the counter e. m. f. must have been generated. Moderately large currents must be used unless the apparatus is light and sensitive, though they should not be large enough to cause an appreciable pinch effect in the part *M*. The vertical parts were made very short and can be neglected (see Fig. 6). Care must be taken to have the whole circuit in a vertical plane, or there will be a disturbing side motion of *W*.

Fig. 4 described over a decade ago is of interest because without exception every one of numerous physicists gave the wrong answer as to the direction of motion, showing how badly our older law had misled us. A horizontal wire *W* is pivoted at *P*, the other end being free to move in a curved mercury trough *M*. It was placed in the position as shown before the current was started; with current it moved in the direction shown, which is the contrary one to that called for by the older law that a circuit tends to expand. The enclosure of the circuit *decreased* instead of increasing. The writer's explanation is that the only part of the circuit which has a freedom of motion to lengthen itself, namely the mercury part, did so. When started on the other side of the "dead point" it of course moved in the opposite direction, for the same reason.

Fig. 5 is a modified form of the classical Ampere trough experiment. *B* is a bridge wire floating on the two mercury troughs *M M*. In the original experiments by Ampere the battery circuit was placed at the left as shown in dotted lines, and the resulting movement of the wire *B* to the right was attributed to the old law that the circuit tends to enlarge itself; also to the repulsion due to that part of the battery wire which is parallel to the bridge wire. The writer attributes the motion to the tendency of the mercury parts of the circuit to lengthen, owing to the lateral pressures of the disks of flux around them; they are the only parts in which this force is free to act. This was shown to be the correct explanation, and the older explanations were shown to be wrong, by reversing the position of the battery cir-

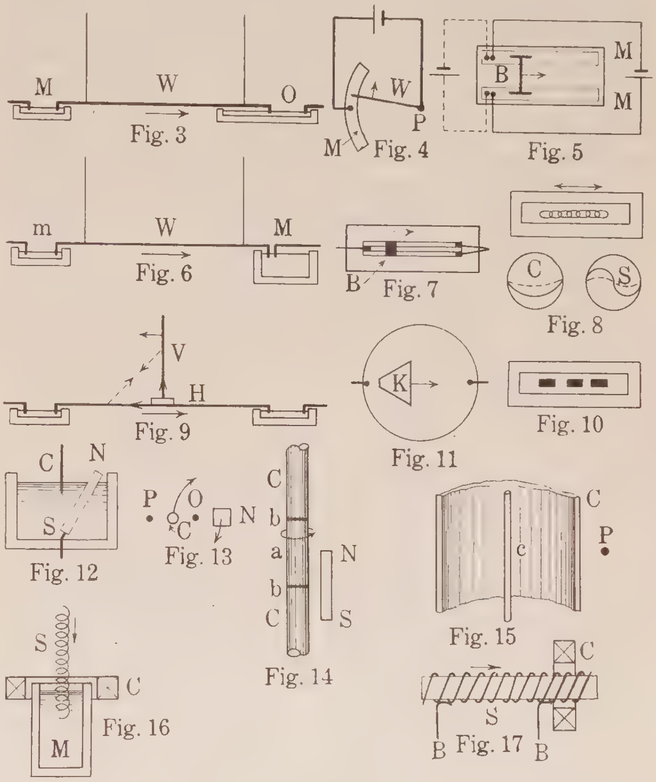

Fig. 3 Fig. 4 Fig. 5 Fig. 6 Fig. 7 Fig. 8 Fig. 9 Fig. 10 Fig. 11 Fig. 12 Fig. 13 Fig. 14 Fig. 15 Fig. 16 Fig. 17

cuit as shown in full lines, as the motion was then in the *same* direction, as it should be, while according to both the older laws it should have been reversed. The battery wires should not be too near the troughs.

It is of interest that Ampere himself thought there was some such longitudinal force in this experiment, but his followers, notably Maxwell, were not convinced; it did not fit in with Maxwell's mathematics.

An interesting feature about this experiment is that, assuming a constant current, the counter e. m. f, is evidently generated in the parts which are added to the lengths of the trough part of the circuit, as these are the only parts around which new flux has been generated, hence it is not essential that the counter e. m. f. must be generated in the part which moves, namely *B*; a motion may therefore be produced if a counter e. m. f. is thereby generated in *any* part of the circuit. While *B* is the part which moves, the forces which move it reside

entirely in the mercury trough parts, and not in B itself, as is generally claimed.

In Fig. 6, a long horizontal wire W suspended so that it has freedom of motion lengthwise, has one end dipping into a mercury trough M the cross section of which is large, and the other end into one (m) in which it is small. For the same current the flux encircling the large cross section in M is of course less in amount than that around m hence the lateral repulsion of this flux in m should be greater than that in M; the wire W should therefore move to the right, which it does quite decidedly.

It was, of course, claimed by the upholders of the old law that this was due to the repulsion of the vertical parts entering the troughs, even though they had been made very short. These were therefore placed as shown, close together in M and far apart in m, yet the movement was still in the same direction though slightly less in intensity; it should have been reversed if caused by those vertical parts. This shows conclusively that the movement was not due to these vertical parts and that the longitudinal forces were greater as they overpowered the others.

Fig. 7 shows a better and simpler way of making the same experiment. Three long slender mercury troughs were made as close together as possible, the walls between them being made as thin as possible. A movable copper bridge piece B floating freely on the mercury, connects them. The meniscus of the mercury projected slightly above the troughs so that the bridge piece had practically no vertical component. Both of the right-angular parts of the bridge piece were therefore made so short that they could be neglected; this was done because it is these right angular parts that the upholders of the older theory depend upon; the previous experiment in Fig. 6, however, in which these perpendicular parts were much longer showed conclusively that even when very much longer than in Fig. 7, they did not determine the motion.

When current was passed into the middle trough and out of the outer two (or all three) the bridge piece moved very decidedly and quite rapidly to the right. The motion appeared to have a constant velocity. The explanation is the same as in Fig. 6, that the flux around the smaller cross section was much greater than around the larger one, hence the longitudinal force of the former overpowered that of the latter. This apparatus is in a more convenient form for a lecture room experiment.

In Fig. 8, a well amalgamated copper chain was laid in a much longer mercury trough in a contracted position so that it could stretch. When the current was passed it immediately and decidedly stretched to its extreme length. Copper being a far better conductor than mercury most of the current passed through the copper, which having a far smaller cross section had much more flux around it than there was around the ends of the mercury trough, hence the longitudinal force overpowered that at the ends. As the copper is likely to be sucked under by the pinch effect (where the stretch effect is also stronger) and disappear while the current is flowing, it is well to float the ends with some light non-conductor.

This experiment also meets the claims sometimes made that in some of the movements in these experiments it is the pinch effect which by its hydrodynamic action in the mercury causes the motion. If the pinch effect were the cause, it would act to push the ends of the chain towards the middle, but the fact is that the movement is in the *opposite* direction. This experiment which requires large currents, might perhaps be more conveniently carried out with much smaller currents by suspending the chain from floats in an electrolyte.

When this chain was laid in a contracted form in circular mercury dishes C and S with its ends secured near the terminals, and in the positions shown by dotted lines, it stretched itself into the positions shown in full lines when current was passed, as a compressed helical spring would do. Repeated short applications of the current seemed to act better.

Fig. 9 is a modified form of an old experiment attributed to Faraday or perhaps to Ampere. It furnishes a different and independent proof of the longitudinal force and one which it is difficult if at all possible to meet by the older laws. In the original a vertical conductor V was mounted so that it could move to the right or left parallel to itself. It contacted with a horizontal wire H which was stationary. When currents were passed in the directions indicated the movable wire V moved to the left.

The writer maintains that as the movement of V was caused by the current in H, then if the apparatus be reversed so that V is fixed and H has a freedom of motion in the opposite direction, the same force would move H in the direction of its length, which it did, thus showing the existence of this strongly denied longitudinal force. This must follow from Newton's third law, that for every action there is an equal and opposite reaction. It also must follow from the view of Ampere and others, apparently endorsed by Maxwell (Art. 527), at least not denied by him, that the force between two elements is along the line which joins them, as shown by the diagonal line. If so, such a direction must have components in the directions of the lengths of both conductors.

It seems strange that although this experiment, the law of Newton, and the views of Ampere, have been known for the past hundred years, this method of proving the existence of the longitudinal force has apparently not been considered before, or if it has it has certainly not been generally known, or had been forgotten, and is still being strongly contested.

In the writer's modification the wire V was fixed and the long wire H was suspended so that it had a freedom of motion lengthwise. When the currents were passed in the directions shown, the wire H moved to the right, or when one of the currents was reversed, then to the

left. The contact between the two was made with a small mercury trough carried by H. When H was fixed and V allowed (by means of a mercury trough) to move in the direction of its length, it so moved away from H. Before the experiment a current was passed through H alone to make sure that no motion was caused by the very short vertical parts that dip into the mercury dishes; moreover the final motion was again in the opposite direction to what it would be if it had been caused by these vertical parts as most physicists will claim, because the current in one pair of ends is necessarily greater than in the other.

It will probably not be denied that the forces involved are concentrated almost entirely at or near the corner where the conductors are nearest together; it is therefore a weak argument to make a crucial point, as has been done, of where the "rest of the circuit" is. Beyond a few inches from the corner the circuits have probably an entirely negligible effect on the forces, and it therefore does not matter where they are. Some physicists have "grabbed at straws" to uphold the older laws, instead of being helpful in trying to improve them.

This same test was also made and exhibited by the writer some years ago, in a different way, resembling more closely the apparatus existing in many physical laboratories to show the original experiment of Faraday. H was a stationary circle and V moved around this circle. In the modified form V was fixed and the circular part moved. Sliding contacts were used to replace the usual liquid conductor and this caused much friction, but still the movement was quite decided, and was witnessed by many.

In Fig. 10 three short pieces of well amalgamated copper wire were floated on a mercury trough in a straight line with their ends close together. When alternating current was passed they separated a short distance as shown, but would move no farther even with repeated applications of the current. This seemed to indicate that the denser field around the copper pieces was, as it were, elastically connected to its conductor and that the repulsion of like lines made it extend itself a slight distance beyond the ends.

Fig. 11 shows an interesting difference between a direct and an alternating current. A kite shaped piece of well amalgamated copper was floated as shown on a circular dish of mercury. The idea was that the denser flux around the main path near the small end would produce a greater longitudinal force than the less dense flux around the much larger main path at the larger end, thus causing the piece to move to the right. With direct current it moved every time the circuit was closed but only for a very short distance and then stopped. An alternating current ought therefore to move it continuously, which it did, across the whole bath and at apparently a constant velocity, always in the direction of the large end forward. This experiment showed that the motion was not due to the pinch effect, as had been claimed, though if the current becomes very great the alleged hydrodynamic resultant of the pinch effect in the liquid conductor will contribute to the motion.

Fig. 12 represents Faraday's ingenious experiment to show that a single pole N of a magnet moves along the circular lines of force around a fixed current-carrying conductor C. This experiment does not seem to be described in his well known Experimental Researches, but was published by him in the *Quart. Jour. of Sciences*, XII, 186, and again with an illustration in the next issue 283; the date seems to be about 1822, just 100 years ago; this description is included in a later collection of his works. Maxwell (Art. 486) refers to Faraday's experiments and shows a figure (Art. 491) which however is totally different from the original and the explanation accompanying it is difficult if at all possible to understand, owing apparently to Maxwell's efforts to include an involved explanation of a sliding contact, necessitated by his mathematical treatment. Faraday's own explanation is very simple and is not burdened with any such complications. The writer could find no illustration in Faraday's works corresponding to the one given by Maxwell.

In Faraday's original experiment a permanent magnet $N\ S$ was floated in a cup of mercury in a slanting position as shown in Fig. 12, with one pole tied with a string to the center of the dish at the bottom. The current entered through the central fixed conductor C and left through the center of the bottom. When current flowed the free pole moved in a circle around the wire C.

The writer repeated the experiment, and found that apparently the chief force was a couple, as shown in Fig. 13, which represents a top view of the upper part of Fig. 12; the conductor C and magnet pole N each endeavored to revolve around the other, as Faraday showed. If linked together and pivoted at O they should therefore revolve around O; if the link is pivoted at P they should revolve less forcibly around P, due to the difference between the two torques; these were not tried.

When the conductor is revolvably mounted on its axis it ought to revolve when the magnet is stationary, according to Newton's third law. The revolving force is then tangential, like the pull on a string wound around the wire, and its effect therefore becomes very small when the diameter is small. By making its diameter large relatively to the distance to the magnet, especially when it is made hollow, the writer obtained decided rotation.

It is of interest that according to Lenz' law when any of these motions are reversed by an external force, a current should be generated.

A result of some interest is that when this experiment is arranged as shown in Fig. 14 in which a large (preferably hollow) fixed conductor $C\ C$ has a part a mounted so that it can revolve on its axis, ($b\ b$ being sliding contacts like a layer of mercury), it revolves when the magnet is placed as shown, parallel to the conductor.

If the magnet were mounted so that it could move around the conductor keeping parallel to itself, it would seem to have to follow that when the part a is forced to rotate there would be some movement of the magnet; this was not tried.

Another deduction is shown in Fig. 15. We are told that for the same current in the small conductor c and in the large hollow one C the magnetic effect on a point P is the same, being the same as though the current were all concentrated at the axis. Yet, as shown above, if a magnet pole be placed at the point P, it will easily rotate C, but c only with great difficulty. And if the current was concentrated at the axis, it would take an infinite force to revolve its conductor. Hence there is some physical difference between the fields around those two conductors and our older law leads us away from rather than toward this difference.

In Fig. 16, S is a solenoid mounted so that it can move down into a mercury cup M. C is a stationary coil. When like, constant, currents were passed through both, S moved downward decidedly. It thereby cuts out some of the ampere-turns, which reduces the flux generated by it; the reluctance of the combination will also be decreased somewhat but presumably in a less proportion, and if so the total flux of the combination would be *less* after the motion than before, thereby contradicting the older law that the flux increases, which it surely does not do in this case. Moreover, the self inductance is surely *less* after the motion than before; the writer had no means for measuring it. The two coils may be assumed to be in series. As actually carried out the mercury was replaced by a fixed brush, as in Fig. 17.

In Fig. 17 the conditions are similar except that the current is now led into the solenoid S by a fixed brush, B; the other brush B at the coil was the same as before. To avoid cutting out and in a whole turn at a time, these brushes may form a complete circle around the solenoid, therefore acting like the surface of the mercury. In this arrangement the magnetic field of the combination remains exactly the same everywhere in intensity and direction, and there is no contraction of the flux as a whole, yet there was very decided motion. The self-inductance evidently also remains constant. There is no commutation. If the lines of force are not considered to be in some way attached to the moving electrons which produced them the troublesome sliding contact must again be called to the rescue to explain it. In the writer's opinion new flux is generated at the distant end of the solenoid as the current is started in new parts of the conductor, this is strongly attracted by the coil C; the flux at the near end which is being cut out, exerts little or no attraction to C; a part of the flux which was generated by both coils together disappears as such by being converted into the kinetic energy of the motion. The flux therefore seems to move with the coil.

Fig. 18 represents a top view of a mercury trough M ending in two large reservoirs of mercury, to which the current connections were also made. When currents is passed the mercury in the trough should stretch thereby moving into the end reservoirs, the flux around it being far denser than around the end reservoirs. It did so, as was shown by a rapid flow of mercury from the middle reservoir R through the short connecting channel and into the trough. In this case there was absolutely no perpendicular component of the circuit on which the upholders of the older laws depend. That this motion was not due to the pinch effect, as claimed by others, is conclusively shown by the fact that if it were, the mercury in the small connecting channel should have flowed in the *opposite* direction; the action of the pinch effect would be a compression of the liquid in the trough, which would cause it to flow into all three reservoirs.

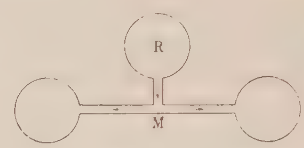

Fig. 18

General

It has been claimed that some of these experiments are "tricky" and therefore are not worthy of notice. The writer however maintains that a law to be universal must not have a single exception; if it has then possible progress in new fields is forbidden by it.

The writer desires to express his thanks to the departments of Physics and of Electrical Engineering at the University of Pennsylvania for the courtesy of extending to him the use of their laboratories for demonstrating some of the experiments. Also to Prof. R. E. Brown of Philadelphia for his encouraging cooperation in some parts of these researches. Also to the many physicists and electrical engineers whose antagonistic attitude during the past decade led the writer to a number of new and apparently significant experiments.

Conclusion

As a basis for discussion the writer suggests tentatively the following general outline of a proposed revision, in logical sequence, of the older laws, and of their mathematical treatment, assuming that the correctness of each step has been, or will first be, sufficiently conclusively demonstrated.

Starting with the tension along a straight line of force (the pull between magnets) as the most basic fundamental, deduce from it the repulsion of like lines and the radial force on the conductor, from the principles of hydrodynamics; then the two forces in a single conductor, the pinch effect and the stretch effect, which are independent of the length; then those between unit lengths of conductors, and those between magnets and unit lengths of conductors. Omitting the ether, recognize that the forces in a field are an action at a

distance, having their abutments in the material of the conductors or magnets, and that therefore the imaginary lines of force must be picturized as having some physical elastic connection with their source, the moving electron. Formulate in electrical terms a general law of motion (like the one suggested above) based on the long established general law in mechanics concerning the self-conversion of potential into kinetic energy. Finally on this law, combined with the Lenz law, base the general law of generators, that is of induction.

Appendix

The following is the mathematical solution by Prof. Richard E. Brown of Philadelphia, of the problem referred to above. The problem is: two like copper rings on the same axis, are reduced to 0 deg. absolute, at which their resistance is zero; like and equal currents are induced in them by drawing a magnet through them once, which currents will then continue to flow indefinitely (there is no outside source of supply); the energy put into the system is stored in the magnetic field. Let their attraction move them nearer to each other, thereby setting free kinetic energy at the expense of their potential energy; their flux energy and the currents will thereby have been reduced; (the reverse motion would increase the currents.) The question is, will the total flux of the combination have been reduced thereby.

The combined flux energy of two like coils carrying the same current, as though connected in series, is $1/2\, L i^2 = 1/2\, l i^2 + 1/2\, l i^2 + M i^2$ in which i is the current, L the self-inductance of the combination, l that of each coil separately, and M the mutual inductance; the sign of $M i$ is plus because the fluxes are in the same direction.

The total flux linking any coil is: self-inductance multiplied by the current and divided by the number of turns; there is only one turn per coil in this case.

Assume the current carrying rings to be so far apart that there is no mutual inductance, and then to move toward each other until they coincide (theoretically), the current i being at first assumed to be maintained constant during this motion by some outside source, hence at the end there will be one coil of two turns; they are at first assumed to be filamentary, having no thickness.

When the rings are far apart (no mutual inductance):
magnetic energy $= 1/2\, l i^2 + 1/2\, l i^2 = l i^2$
self inductance of combination $= L = 2\, l$ because the energy $1/2\, L i^2 = l i^2$
total flux of combination $= l\, i + l\, i = 2\, l\, i$

When the rings coincide:
magnetic energy $= 1/2\, l i^2 + 1/2\, l i^2 + l i^2 = 2\, l i^2$
self inductance of combination $= L = 4\, l$ because $1/2\, L i^2 = 2\, l i^2$
total flux of combination $= 4/2\, l i = 2\, l\, i$.

Hence when the current is assumed to be maintained constant, the total flux remains constant during this motion, and the magnetic energy would be doubled, being supplied from the assumed source which maintained the current constant. But in the above problem there is no such source and there must of course be less magnetic energy in the combination after the motion than before by the amount of kinetic energy given off by the self produced motion. Hence the current must have *decreased*, and as the total flux was shown above to remain the same when the current is kept constant, it follows that with a decreased current the total flux will have *decreased*.

The writer here calls attention to the fact that in the above the self inductance of the combination has been doubled by this motion, on the assumption that at the end there is one coil of two turns. The flux and flux energy, however, and therefore the forces, are quite independent of whether there are then two turns with a current i or one turn with a current $2\, i$, as for instance if the rings were of mercury or of liquids in a furnace. In the latter case, the self inductance would be halved at the end of the motion instead of doubled. This shows again that the self inductance is a wrong term to use as a crucial one in such a law; also that in practise the self inductance may actually decrease. The fact that in practise when two such material rings coalesce (the single ring having double the original current per ring) the flux will be somewhat less than double that of a single ring, (because both the cross section and the current have been doubled) shows that the self-inductance may be even still less than a half.

In the case of the attraction of two permanent magnets, it seems self-evident that not only the total flux energy but the total flux itself, of the combination, is *less* after the motion than before, thus disproving the older law that it always increases. At the neutral part of such a magnet, if it is a good one, it is presumably saturated, hence after they are in contact the flux in that part of each one cannot be assumed to have practically doubled, which would have to be the case if the total flux did not change, or more than double if it increased with the motion.

Prof. Brown's tests confirmed this in the following way though he says the tests were somewhat crude. By the total flux in a U-shaped permanent magnet is here meant the flux in the magnet at its netural point (at the curved part). This was measured approximately by means of a galvanometer and a coil around the keeper, while it was being attracted; call this F. The change of flux at the neutral point of one of the two like magnets was then measured while the other was moved into contact with the first; call this f. This quantity f was found to be less than F, showing that the total flux of the combination was less after the motion than before, that is, less than double that of one magnet. Some flux as well as flux energy has therefore disappeared.

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ELECTRIC TELEMETER

During the past two years or more, the Bureau of Standards has been engaged in developing electric telemetric devices based upon the fact that carbon contact resistances vary with pressures or displacements applied to their terminals. Many attempts have been made in the past to utilize this principle for various engineering and scientific measurements, particularly in those cases in which it was desirable to place the indicating or recording instrument at a considerable distance from the actual member or element under test, but until recently no success has been met with. The trouble in the past has been due to several inherent difficulties with apparatus of this kind. In the first place, as heretofore used, these carbon contact resistances have been very erratic in their performance and the constancy of their calibration could not be depended upon sufficiently to warrant their application to ordinary engineering uses. A second difficulty has been due to the fact that, as heretofore used, such apparatus has shown large hysteresis effects, that is, the indications of the apparatus have been very different on rising pressures or displacements than for the same values approached from a higher limit. Errors due to this cause usually reached from 20 to 50 per cent or even more.

A third difficulty grows out of the fact that these devices are inherently non-linear in their characteristics, that is, the readings of the indicating instruments are not proportional to the pressures or displacements that are being measured,—a characteristic which is very objectionable in most engineering work. The Bureau has investigated all of these sources of trouble and has found means of eliminating all of them to a degree which makes the apparatus well adapted to a great variety of engineering measurements. These include measurements of strains in bridge members and other engineering structures, measurements of accelerations, vibrations, and pressures of practically every description. The apparatus can be made either indicating or recording as desired. Up to the present time both indicating and recording instruments embodying this principle have been made for and largely used by the Bureau of Aeronautics of the Navy Department for measuring stresses both in airplane members and dirigibles where it is very important to read such stresses at a point more or less remote from the member under test. Similar apparatus has also been used extensively by the Bureau of Standards in laboratory tests on large structural members and also in connection with certain dynamometer work, and for much of this work the new instruments have been found to be substantially equal in accuracy to anything heretofore available in the line of indicating instruments, and they possess the additional advantage of permitting remote reading as well as graphic records to be made when desirable.

DETERMINATION OF THE MAGNETIC PROPERTIES OF SHORT BARS

The growing interest among engineers and designers in the correlation of the magnetic and other physical properties of iron and steel has given impetus to the study and development of methods for making the necessary magnetic measurements. Many materials of an experimental composition or of extreme purity are available only in limited quantities, and the ability to obtain magnetic measurements on small samples would be of decided advantage both from the point of view of economy of material and because of the ease of the machining and heat treatment.

The direct determination of the magnetic properties of small samples with any degree of accuracy is a difficult matter, but the Bureau of Standards has recently developed an apparatus capable of measuring the magnetic properties of such a sample with a satisfactory degree of precision. The method involves the comparison of a sample of the material to be tested, which is in the form of a cylindrical bar 6 mm. in diameter and 10 cm. long, with a reference bar, the apparent magnetic properties of which have been determined through calibration by means of standard bars having accurately known properties. This method is capable of giving results accurate within 5 per cent for most materials.

Physical Interpretation of Complex Angles and Their Functions

BY ARAM BOYAJIAN
Member, A. I. E. E.
General Electric Co. Pittsfield, Mass.

Review of the Subject.—A child's idea of an angle is a corner or edge; the sharper the corner or edge, the smaller is the angle, and hence expressions like "acute (sharp) angle," "obtuse (blunt) angle," etc. With a little schooling his idea of an angle is broadened into that of turning or rotation and finds a geometrical expression in a circle. The amount of turning is represented by the area of the sector of the circle like a piece of pie gone over by the turning radius. This broadened idea is still in agreement with the earlier idea because the sector is a surface having a corner at the center of the circle, and the sharpness or bluntness of this corner varies with the area. With further progress, he also learns to associate the angle with the arc of the circle, for, evidently, the length of the arc is a measure of the amount of turning and is proportional to the area of the sector. The angle when represented by the arc of the circle loses all resemblance to a corner, which latter idea however is discarded as unnecessary, emphasis now being laid on "turning" which is well represented by the arc of the circle. Mathematical analysis is then applied which still further broadens the scope of angles and gives rise to the so called "imaginary" angles which are called "hyperbolic" in contrast with ordinary "real" angles which are called "circular," combinations of these two kinds of angles being called "general" or "complex." At this stage, any physical interpretation or geometrical representation of an angle practically vanishes, for, a hyperbolic angle can not be conceived of as a rotation, not even as a rotation around an "imaginary" axis, for, how can one conceive of an "imaginary" axis? If the "imaginary" axis be defined as a new axis at right angles to the old axis, rotation around it can easily be conceived of, but it does not correspond to facts, because a hyperbolic angle implies no change in direction, and hence no rotation, but merely affects the magnitude of a quantity. Inasmuch as problems can be solved mathematically without any visualization, the mathematician discards visual interpretations and bases his conceptions on formulas. However, the engineering type of mind finds it both difficult and distasteful to be dependent on symbolic definitions, and craves for visualization. He feels that if physical problems lead to "imaginary" or "complex" angles, these angles must stand for some concrete physical facts and must therefore be capable of a physical interpretation.

A broad and yet simple physical interpretation applicable to both circular and hyperbolic angles is developed below, which also applies to their trigonometric functions, as follows:

A quantity may be expressed or specified either by its own dimensions or as a percentage of another quantity. The first kind of specification is its "absolute" measure, the second kind is its "angular" measure. Thus "angle" and "percentage" are synonymous terms. If a quantity changes by a certain percentage (compound percentage as in compound interest) that "percentage" is the "angular" change in the quantity in radians. According to this interpretation, neither corner, edge, turning nor rotation are essential characteristics of an angle; they are the characteristics of a limited class only. If the percentage change in a quantity is like itself, geometrically parallel to itself, the per cent change, that is, the angle, is called a hyperbolic angle, and there is no rotation. If the quantity varies without any change in magnitude but only with a change in direction, geometrically perpendicular to itself, the per cent change, that is, the angle, is called a circular angle, and there is rotation. Thus, hyperbolic and circular angles are at right angles to each other, the first being a per cent change parallel to the quantity, and the second perpendicular to it. "Imaginary" thus means a quadrature. However, it is not rotation around a quadrature axis but per cent change in a quadrature direction.

This new interpretation is in agreement with the representation by arcs in a more extended vectorial sense in which one is not limited to the arc of a circle but arcs of any shape have an angular interpretation. Thus, consider a portion of an arc of any arbitrary shape, and resolve it into two components, one circular (at right angles to the radius drawn to the point) and the other straight and radial (parallel to the radius at that point). These two arcs expressed as a percentage of the radius represent circular and hyperbolic angles, respectively, and being in quadrature with each other their vector sum is the "complex" angle of the arc. In this interpretation a hyperbola has nothing to do with a hyperbolic angle, and the name is unfortunate. It would have been more intelligible to speak of the ordinary circular angle as a "quadrature" angle, and of the so called hyperbolic angle as a "linear" angle or a "radial" angle.

This new interpretation of an angle is then utilized to interpret the physical significance of sines and cosines of angles, whether circular or hyperbolic. The common idea of a cosine as the projection of the radius vector on the X axis, and of sine as the projection on the Y axis, is found inadequate, this idea being limited to circular angles and not being of much value in explaining their occurrence in physical problems. A cosine is then interpreted as the mean vector value of a unit quantity for a given per cent increase and an equal per cent decrease, or a given value of rotation positive and negative. Examples are given illustrating the application of this vector idea in physical problems, as in the resolution of a harmonic wave into two oppositely rotating vectors, solution of differential equations, etc. A geometrical construction is given for the sines and cosines of complex angles, which is not merely a representation but photographically true, so to speak.

Introduction

THE student of trigonometric functions finds by some dark analytical transformations that the sines, cosines, etc., of imaginary angles are not impossible or absurd quantities but resolve themselves into hyperbolic functions of those angles looked upon as real angles. Thus if θ is an "ordinary" angle, that is, a circular angle,

$$\cos (j\,\theta) = \cosh (\theta) \tag{1}$$

$$\sin (j\,\theta) = j \sinh (\theta) \tag{2}$$

$$\tan (j\,\theta) = j \tanh (\theta) \tag{3}$$

These identities indicate that a hyperbolic angle is j with respect to circular angles, and the questions naturally arise: (a) Wherein is a so-called hyperbolic angle an angle at all? (b) Wherein does it differ from ordinary angles? (c) What is the physical significance of its being j with respect to the ordinary angles?

1. All percentages, in this paper are supposed to carry their decimal points explicitly. Thus, ten per cent is to be given as 0.10, not merely as 10.

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The usual representation of hyperbolic angles and functions by means of a hyperbola, as circular angles and their functions are represented by circles (See Figs. 1 and 2), completely fails to throw any light on these questions; the representation merely serving the purpose of giving an idea of their numerical values but not of their physical nature. Certainly, it is not evident from these figures wherein the area of the hyperbolic sector representing the hyperbolic angle is j with

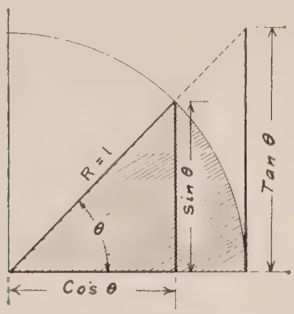

Fig. 1

respect to the circular sector representing the circular angle. Furthermore, it is not evident wherein the hyperbolic sine and tangent are j with respect to the circular sine and tangent, while the hyperbolic cosine is "real" like the circular cosine. These points not being explainable on the basis of representation by a hyperbola, it is not to be expected that an explanation can be given on that basis of the physical significance

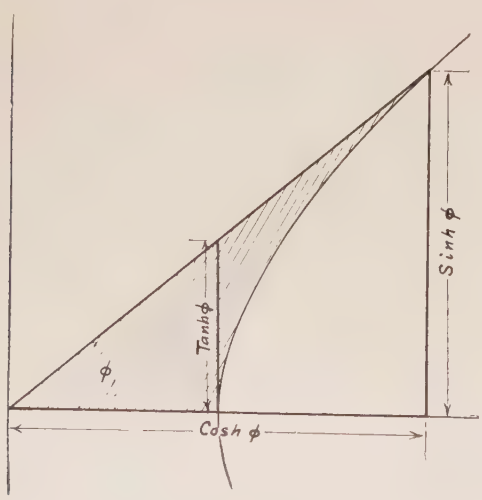

Fig. 2

of the so-called imaginary periodicity of hyperbolic functions, as in the equation

$$\cosh(\theta) = \cosh(\theta + 2\pi n j) \tag{4}$$

Evidently, we need first to develop a simple physical interpretation of what an angle is in its most general sense, a physical conception which will apply to hyperbolic angles as well as to circular angles and will show their natural relationship. Then we must develop a physical interpretation of trigonometric functions, broad enough to include both types, and clear enough to show their relationship.

It will be shown below that an angle, in its broadest sense, is nothing more or less than a *percentage*, more specifically a percentage change in a quantity, the percentage being *compound* not simple percentage, effective at every point or instant, as for instance in compound interest. It will, then, be shown that an imaginary angle is nothing more or less than a quadrature angle, that is, one in quadrature with the circular angle. This is in accordance with the use of j in engineering as a quadrature operator, is consistent with the mathematics of hyperbolic trigonometry and leads to an extremely simple physical interpretation of the imaginary periodicity of hyperbolic functions, *viz.*, that their periodicity is not imaginary or unthinkable but in quadrature with themselves. The point of view is evidently vectorial. Since the arc represents the change in a vector vectorially, the component of the arc in quadrature with the vector represents the circular angle, the component parallel to the vector represents the hyperbolic angle, and the arc as such represents the complex angle. From this novel point of view all imaginariness disappears from the trigonometry of complex angles, and the various relationships usually established by tedious mathematical transformations become almost self-evident physical facts. We must therefore analyze this new interpretation in somewhat greater detail.

Physical Meaning of an Angle in Its Broadest Sense

Let the radius vector R move and trace an arbitrary curve, as shown in Fig. 3. On this curve consider any two adjacent points p_1 and p_2. The arc between these two points represents the vector change in R and we shall designate it in the usual way as dR. Now, a radius vector can move or change in only two essentially different ways, *viz.*; (1) parallel to itself, stretching or shrinking, and, (2), at right angles to itself, rotating. Any other motion can be resolved into two such components, one parallel to the radius vector, the other in quadrature with it. In Fig. 3, the arc dR is resolved into two such components, dR_1 and dR_2. It will be noted that the component at right angles to the radius vector is curved being the arc of a circle, as it must be to keep perpendicular to the radius vector at every successive position of the latter (See Fig. 4). However, if the path dR is taken short enough, dR_2 will be a straight line.[2] It is highly important to note that the two components, dR_1 and dR_2 of dR, are at right angles to each other.

The distance dR which the radius vector covers in its sweep along an arbitrary curve may be given in

2. At a later point in the discussion of angles in three dimensional space, a rigid physical and mathematical justification will be given why the vector angle is represented by the curved line and not by its chord.

either one of two ways: (a) it may be given by its actual value without any reference to the radius vector itself or, (b) it may be given as a percentage of the radius vector. The first method of measuring distances is the absolute way, the second method is the angular way. That is, the length and direction of a path traced by a moving radius vector is the absolute (vector) value of the change; the same path expressed as a percentage of the radius vector is the corresponding angular (vector) value.

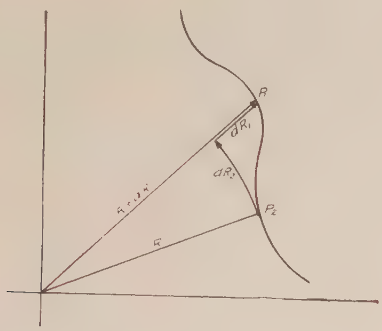

Fig. 3

According to the foregoing, we may write,

Absolute value of path $= d\,R$ (Inches or cm.) (5)

Angular value of path $= \dfrac{d\,R}{R}$ (Radians or percentage) (6)

Both the absolute and the angular values of the path are vectors: thus, treating the radius vector as the zero angle axis,

$$d\,R = (d\,R_1) + j\,(d\,R_2) \qquad (7)$$

$$\frac{d\,R}{R} = \frac{d\,R_1}{R} + j\,\frac{d\,R_2}{R} \qquad (8)$$

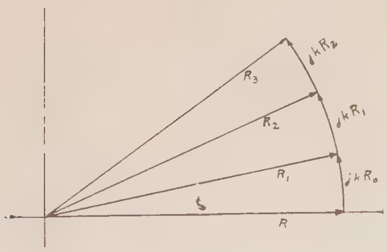

Fig. 4

It is commonly known that $(d\,R_2/R)$ is a small ordinary circular angle; call it $(d\,\theta_2)$. The reader must have already surmised that $(d\,R_1/R)$ is a small hyperbolic angle; call it $(d\,\theta_1)$. Calling the complete vector angle $(d\,\theta)$, we have,

$$d\,\theta = (d\,\theta_1) + j\,(d\,\theta_2) \qquad (9)$$

$$= (\text{hyperbolic angle}) + j\,(\text{circular angle}) \qquad (10)$$

In these equations θ_1 and θ_2 have been considered as "real" numbers, and hence the necessity for attaching j to θ_2. However, if θ_1 and θ_2 were considered vector symbols, as is really logical to do, no separate j would have been necessary. The same statement applies to equations (7) and (8).

To summarize what has been said: a moving or changing radius vector traces a path. This change or path expressed vectorially in per cent of the radius vector is the angular measure of the change or path (in radians) through which the radius vector sweeps. If the radius vector moves perpendicular to itself at every instant, it rotates and traces a circle, and the length of its path in per cent of the radius vector is called a circular angle. If the radius vector moves parallel to itself at every instant, it stretches or shrinks and traces a straight line and this path expressed as a per cent increase (or decrease) in the radius vector is called the hyperbolic angle (in radians) of the path.

If angles are defined by the area which the radius vector covers, as is sometimes done, there would be no physical bond between circular and hyperbolic angles. But, defining an angle by an arc of a path, circular and hyperbolic angles are equally included. If the path is perpendicular to the generating line at every point, it is called circular; if parallel to the radius vector, it is called hyperbolic; if at an intermediate direction with respect to the generating line, it is called a *general* or *complex* angle. The arbitrary path in Fig. 3 represents a complex angle. It is physically evident that circular and hyperbolic angles (as arcs or paths) are j with respect to each other, that is, they are in quadrature. Furthermore, it is more correct to call the circular angle and not the hyperbolic angle (arc) the j angle, because the circular arc is in quadrature with the reference line, the radius vector; while the hyperbolic angle (arc or path) is in phase with it.

In Fig. 3, if $d\,R_2$ is rotated through 90 degrees, into parallelism with $d\,R_1$, it becomes a hyperbolic angle. That is, $j\,\theta$ circular angles are equal to θ hyperbolic angles.

When the radius vector moves perpendicular to itself, the term "circular" for the resulting angle may be appropriate because the path is circular, but it does not appear at first very clear why, when the radius vector moves parallel to itself, only stretching or shrinking, the resulting angle should be called hyperbolic. Historically, the reason for this nomenclature has been the fact that by certain graphical constructions a hyperbola is made use of to evaluate hyperbolic angles and their functions in the way a circle is utilized for circular angles as illustrated in Figs. 1 and 2. This, however, is likely to lead to the erroneous idea that when the radius vector is tracing a hyperbolic angle it is tracing a hyperbola, for it traces a straight line not a hyperbola. Hence, it appears that the two kinds of angles could be designated more appropriately as "circular" angle for one and "linear" angle for the other, or, "quadrature" angle for one and "in phase" angle for the other. Furthermore, so far as graphical constructions are concerned, we are not limited to the hyperbola, but more direct, and perhaps simpler, constructions are available in which the circular and hyperbolic angles

and their functions are shown in their true physical nature and relationship.

It is to be observed that according to this new interpretation the characteristic which constitutes an angle is not *turning*, but just a *per cent change*, and therefore, it is not necessary to assume that hyperbolic angles are produced by the rotation of the radius vector around an "imaginary" axis in an "imaginary" plane as is sometimes suggested as explanation.

How to Calculate the Angle of a Path

When the radius vector R moves at right angles to itself, at every instant, its length is unchanged, and therefore, if we start with a radius vector of unit length, and let it trace a circle, the angle $(d\,R/R)$

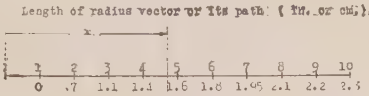

Fig. 5

will always be equal to $(d\,R)$ numerically. Therefore, in circular angles, the length of the arc is also a direct measure of the angle, but in hyperbolic angles, where the radius vector is moving parallel to itself and continually changing in length, the hyperbolic angle, $(d\,R/R)$, can not be represented by $(d\,R)$ numerically. Hence, the scale of a hyperbolic angle continually changes.

Consider now a unit radius vector R along the X axis, (Fig. 5), and let it move along this axis generating a pure hyperbolic angle. Some time the radius vector will reach the point X. The question is, "What is the measure of hyperbolic angle which the path of the radius vector covers?" Or, in plainer language, what is the present change in the radius vector? Since the length of R has been changing every instant, we can not divide the length of path by the initial value of the radius vector, that is, unity, nor by the final value, but we must calculate the angle for very short intervals and add them. In calculus language, the hyperbolic angle described by the radius vector in its travel from 1 to X is

$$\theta = \int_1^x \frac{d\,x}{x} = L\,n^{3}\,(x) - L\,n\,(1) = L\,n\,(x) \qquad \textbf{(11)}$$

This shows that the hyperbolic angle subtended by a straight line based on its initial portion of unit length is equal to its natural (or hyperbolic) logarithm, (and there is thus one reason why such an angle may be called hyperbolic), although, in referring to this feature, "logarithmic" angle may be a better name.

A few points of interest are to be noted in connection with equation (**11**) and Fig. (**5**).

(1) It will be seen that "natural log of path," "angle covered by path" and "per cent length of path" are all equal and synonymous.

(2) The angles indicated are for a stretch of the radius vector from the point 1, *i. e.*, from the end of the unit radius vector, with which we started (not from O), to any desired point along its length. At the starting point, *i. e.*, at R equal to 1, the angle is zero. If the radius vector shrinks, instead of stretching, starting with a unit value, it generates a negative angle, which also is to be seen in Fig. 5.

(3) Due to the fact that the angle of the path is equal to the logarithm of the path, the positive angle increases very slowly as compared with the length of the path. Thus, when the radius vector or path is 10, the angle is 2.3 radians; but when the length is ten millions, the angle is only 23 radians (See Fig. 6).

(4) The reverse of what is true for positive angles is true for negative angles. Thus, the radius vector in shrinking from unity to zero generates an infinite negative angle (See Fig. 5).

(5) Ordinarily, it is not the angle at a point X (that is, between 1 and X) but between two points X_1 and X_2 which is desired, and which evidently is given by $L\,n\ (x_2) - L\,n\ (x_1)$.

(6) The radius vector is essentially positive, and, therefore, no matter in what direction it is drawn, it traces a positive angle if increasing, negative angle if decreasing, and therefore, it is impossible to get a negative radius vector or quantity, which also explains in a physical way the mathematical fact that "ordinary" logarithms do not apply to negative numbers. However, it is possible to transcend the "ordinary" even in the matter of logarithms as will be shown at a later point.

(7) Considering Fig. 6 it will be observed that the angle is graduated uniformly or arithmetically, whereas the radius vector or its path is graduated exponentially

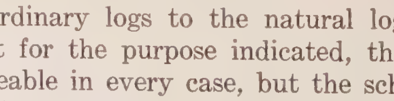

Fig. 6

or geometrically with the object of covering a wide range, as in a slide-rule, the diagram corresponding to 2.3 unit length rule; the factor 2.3 arising from the ratio of ordinary logs to the natural logs. Though convenient for the purpose indicated, this scheme is not serviceable in every case, but the scheme of Fig. 5, in which the radius vector is graduated uniformly and the angle logarithmically, is applicable universally, as will be noted particularly in deriving the trigonometric functions of complex angles.

Before proceeding to the analysis of somewhat more involved aspects of the subject, it may be profitable at this point to tabulate the substance of the foregoing analysis both in every day and in mathematical language in two parallel columns for convenient comparison and greater intelligibility.

3. We shall use $L\,n$ to designate natural logarithms, and "log" to designate ordinary decimal logarithms.

An Exposition of Angles in General

In Mathematical English

1. Let the radius vector R describe an arbitrary path.

2. The path divided by the radius vector is the angle in radians subtended by the path at the radius vector.

3. Any portion of the path may be resolved into two components, one parallel to the radius vector, the other perpendicular to it.

4. The "in phase" component of path divided by the radius vector is the hyperbolic angle in radians.

5. The angle generated by the radius vector per unit of time is called its "angular velocity" in radians. This applies to all kinds of angles, whether hyperbolic, circular, or the combination of the two, that is, general or complex.

6. If the path of the radius vector is at right angles to itself the path is then circular and expressed as a fraction of the radius vector is called a "circular angle" in radians. The circular angle (path) being perpendicular to the radius vector, is therefore perpendicular to the hyperbolic angle (path) which is parallel to the radius vector.

7. The angle which the rotating radius vector tends to produce per unit of time is called its angular velocity in radians per unit of time, as covered in art. 5.

In Every Day English

1. Let a quantity R undergo any arbitrary change.

2. The change in the quantity R divided by R is a fraction and gives the change as a percentage of R. A *per cent* change is called *angular* change in mathematics.

3. The change, or per cent change, in R may be one of magnitude only, or it may be one of direction only. A general change may imply a certain per cent change in magnitude and a certain per cent change in direction.

4. A per cent change in magnitude has different names in practise, such as, *per cent (compound) interest* in banking; *per cent discharge* in hydraulics; *per cent decay* in electrical and radioactive problems; and, in general, as "per cent gain," or *per cent loss*. These percentages are called "hyperbolic angles," in mathematics. One hundred per cent is considered the unit of angles and is called one radian.

5. The per cent change which is produced per unit of time is called the "per cent rate of change" in general, when the change is one of magnitude only, as for instance, "per cent *rate* of (*compound*) interest," "per cent *rate* of discharge" of a reservoir or of a condenser, "per cent *rate* of decay" of a radioactive substance, etc. A "per cent rate" is called "angular velocity" in mathematical language.

6. If the quantity under consideration has direction as well as magnitude, it can change its value without changing its magnitude, that is, it can rotate. The change is then called "angular" in ordinary language as well as in mathematics and is specified in a number of ways, such as revolutions, or right angles, or degrees, or "radians" the latter term meaning the length of the arc (along which the rotation takes place) in per cent of the length of the rotating line, very similar to the per cent change in magnitude, but unfortunately this method of measuring circular angles is not commonly appreciated although it is a very natural method, if not the only natural method.

7. The angle which the rotating quantity tends to produce per unit of time is called its "angular velocity" and is ordinarily measured in revolutions per minute, although a more natural way (in fact, in a sense, the only natural way) to measure or specify it would have been in "per cent radius" *e. g.* (that is, radians, for, radian means per cent radius) per unit of time. For instance, to say that the angular velocity is five radians per second means that a point at the end of any assumed radius covers a distance equal to five radii in one second. In other words, the natural way of specifying an angular velocity is to specify the tangential velocity as a percentage of the length of the radius. Although the popular mind has grasped the fundamental concept of percentages in linear changes, unfortunately it has not grasped the idea of percentages in quadrature or rotary changes.

In Mathematical English (continued)

8. In speaking of arcs as subtending angles, the angles are not subtended at the origin or at any other *point*, but at the radius vector. Hence is the necessity for dividing the arc by the radius vector to obtain the angle.

9. When the radius vector is varying in magnitude, the angle of an arc is obtained by the summation

$$\int_{R_1}^{R_2} \frac{d\,R}{R} = L\,n\;R_2/R_1$$

Let the two limits of integration be 20 and 30 respectively.

$$\begin{aligned} L\,n\,(1.5) &= 2.3 \times \text{Log}\,(1.5) \\ &= 2.3 \times 0.176 \\ &= 0.405 \text{ hyperbolic radians.} \end{aligned}$$

In Every Day English (continued)

8. In speaking of change (of either kind) as a per cent change, the percentage is based on the value of the quantity in which the change is taking place. This point so clear in ordinary language is not so clear in mathematical definitions.

9. When the quantity is varying in magnitude, the change must be expressed not in per cent of the initial value of the quantity, nor of the final but of a mean equivalent value. When only a very small change is considered, the mean value of the quantity is sufficiently approximated by either the initial or the final value or the arithmetic mean of the two. For considerable changes an arithmetic mean value of R will not do, but the percentage may then be calculated in a number of steps as in compound interest. For instance, if the quantity changes from 20 to 30, the percentage of the first unit gain is 1/20.5, the second 1/21.5, the third 1/22.5, etc. and the sum of ten such terms gives the total percentage gain (approximately) which in this case adds up to 0.405, (what is called forty and a half per cent) and happens to check the correct answer in this case to the third significant figure.

The Radius Vector

When the radius vector is given, the angle θ between itself and the unit radius vector R_1 of zero angle is,

$$\theta = L\,n\,R - L\,n\,R_1 = L\,n\,R/R_1 \qquad (12)$$

Fig. 7

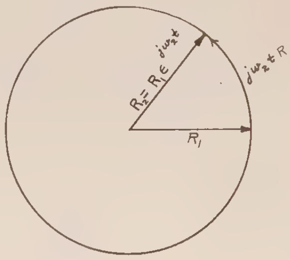

Fig. 8

$$\text{Hence} \quad R = R_1\,\epsilon^{\theta} \qquad (13)$$

This last result gives a physical interpretation to the exponential function as follows. If a quantity, with any initial value R_0, changes (θ) radians, *i. e.*, (θ) per cent (compound percentage), its value becomes,

$$R_\theta = R_0\,\epsilon^{\theta} \qquad (14)$$

The percentage (θ), however, may have any complex value. It may be a "real" number, so called, in which case the quantity has varied in magnitude only; or it may be a quadrature number, in which case the quantity has varied at right angles to itself, that is, rotated; or again, it may be a complex number, in which case the quantity has both rotated and changed in length. In the foregoing, (θ) is taken as the total complex angle.

If the quantity is varying continuously, it traces a path or curve. Assuming the velocity constant: if it is "real," that is, like itself or in-phase, as in

$$R = R_1\,\epsilon^{w_1 t} \qquad (15)$$

the path is a straight line (Fig. 7). If the angular

velocity is imaginary, that is, quadrature, as in

$$R = R_1 \epsilon^{j w_2 t} \quad (16)$$

the path is a circle (Fig. 8); and, if the angular velocity is general or complex, with in phase and quadrature components as in

$$R = R_1 \epsilon^{(w_1 + j w_2) t} \quad (17)$$

the path is an exponential spiral[4] (Fig. 9). The circle applies to undamped harmonic waves; the straight line, with exponential scale, (usually plotted to rectangular coordinates as increasing or decreasing exponential), applies in general to the uniformly damped d-c. or non-periodic quantities; and, the exponential spiral applies to uniformly damped harmonic quantities like the oscillatory discharge of a condenser, etc. The increasing exponential spiral and the decreasing exponential spiral are the images of each other as from a mirror, or an increasing exponential spiral may be considered as decreasing by reversing the direction of rotation, and vice versa.

The exponential spiral of Fig. 9 is of particular interest, for it gives the value of the radius vector both in magnitude and phase angle for any given complex angle. This is the only direct physical representation of the radius vector as it traces a complex angle. In fact, we might speak of it as the *photograph* of the radius vector as it traces a complex angle, in contrast with other graphical constructions which may in some sense be considered as a *representation.* The frame of the exponential spiral deserves special consideration, for it forms the basis of the physical interpretation as outlined in this paper and will be made use of in obtaining the sines and cosines of complex angles. This framework is shown in Fig. 10 as two systems of mutually perpendicular lines; a system of radial lines and a system of circular lines, with common center or origin. The radial lines are graduated logarithmically and measure the hyperbolic angles in radians; the circular lines are graduated uniformly and measure the circular or quadrature angles in radians. The two sets of angles are at right angles to each other as they ought to be. Given the circular and hyperbolic components of a complex angle, the corresponding point is at once located. The vector from the origin to this point gives the radius vector in magnitude and phase angle. The magnitude of the radius vector is measured linearly to some scale. Example: find the radii vector R_1 and R_2 which have the angles $+ (0.5 + j\,\pi/6)$ and $- (0.5 + j\,\pi/6)$ respectively (Fig. 10). It will be observed that the hyperbolic angle determines only the magnitude, the circular angle the direction of the radius vector. Thus,

$$R_1 = \epsilon^{+0.5} (\cos \pi/6 + j \sin \pi/6) \quad (18)$$

$$R_2 = \epsilon^{-0.5} (\cos \pi/6 - j \sin \pi/6) \quad (19)$$

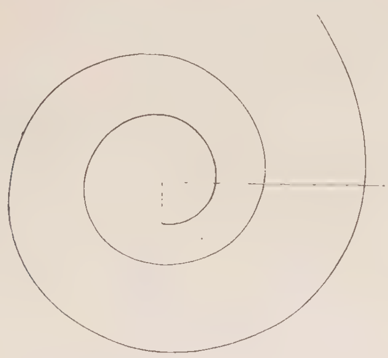

Fig. 9

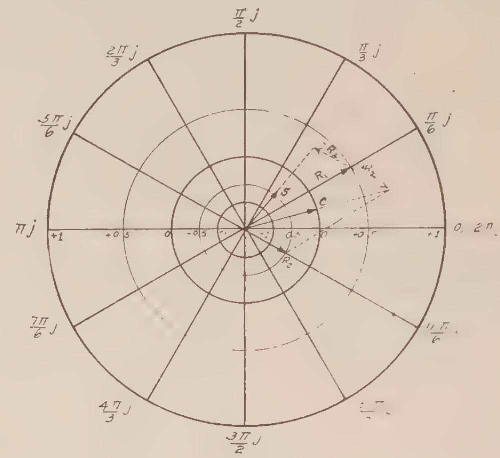

Fig. 10

4. Ordinarily called a "logarithmic spiral." Exponential and logarithmic functions are merely the inverse of each other.

Logarithms of Negative Numbers

In the expression for the radius vector R, having an initial value R_1 of plus unity with zero angle,

$$R = R_1 \epsilon^{\theta} \quad (20a)$$

or

$$R/R_1 = \epsilon^{\theta} \quad (21b)$$

if we assume (θ) as equal to (πj), the radius vector rotates through π circular radians, that is, 180 deg. and becomes minus unity, and we have,

$$R/R_1 = \epsilon^{\pi j} = -1 \quad (21)$$

But in the general expression,

$$R/R_1 = \epsilon^{\theta} \quad (22)$$

(θ) is the logarithm of (R/R_1) and, therefore, from

$$R/R_1 = \epsilon^{\pi j} = -1 \quad (23)$$

we must conclude that (πj) is the logarithm of (-1). This solves the problem of what the logarithm of a negative number could be. Thus,

$$Ln(-x) = Ln(-1)(x) \quad (24)$$

$$= Ln(-1) + Ln(x) \quad (25)$$

$$= \pi j + Ln(x) \quad (26)$$

Physically, it means this:

In the discussion of hyperbolic angles especially in connection with Fig. 5, it was seen that "angle," "percentage" and "logarithm" were synonymous terms. Since, as it has already been shown that "angle" and "percentage" are synonymous terms for circular angles as well as for hyperbolic angles, therefore, we may

extend our idea of a "logarithm" and identify it with "circular" angles as well as with "hyperbolic" angles. The foregoing mathematical transformation can then be obtained by an extremely simple physical reasoning. Thus, considering $(+1)$ as a unit radius vector at zero angle.

(1) What is the angle of $(+1)$? 0 (27a)

" " " logarithm of $(+1)$? 0 (27b)

(2) What is the angle of $(+j)$[5] ? $j\,\pi/2$ (28a)

" " " logarithm of $(+j)$? $j\,\pi/2$ (28b)

(3) What is the angle of (-1) ? $\pi\,j$ (29a)

" " " logarithm of (-1) ? $\pi\,j$ (29b)

(4) What is the angle of $(-j)$[6] ? $3\,\pi\,j/2$ (30a)

" " " logarithm of $(-j)$? $3\,\pi\,j/2$ (30b)

(5) What is the angle of $(+1)$[7] ? $2\,\pi\,j$ (31a)

" " " logarithm of $(+1)$? $2\,\pi\,j$ (31b)

These examples not only illustrate the case of the logarithms of (j) besides that of (-1) but, comparing item No. 1 with No. 5, it is seen that a logarithm is periodic with a quadrature periodicity. That is, adding or subtracting $2\,\pi\,j$ or an integral multiple of it to a logarithm leaves its value unaffected. This, however, need not startle us, for any kind of quantity is periodic for that matter; that is, rotation through $2\,\pi$ circular angles brings a quantity back to its original value. This, then, is the physical meaning of the imaginary, that is quadrature or circular, periodicity of hyperbolic functions, a characteristic true not exclusively of hyperbolic functions but of circular functions and of every other function as well. The reason why this appears like a mathematical mystery to many is simply due to an incorrect trigonometric nomenclature by which, instead of making a distinction between real (that is, linear or in-phase) and circular (or quadrature) angles, calling linear angles (θ), and circular angles $(j\,\theta)$, and having only one kind of sine and one kind of cosine, we have two kinds of angles and two kinds of trigonometric functions. It is probably not too much to think that the early workers who established these nomenclatures had only a hazy conception of these physical relationships. Ordinarily, a circular angle is written as (θ) instead of $(j\,\theta)$, and the periodicity of the trigonometric functions is given by an equation like

$$\cos(\theta) = \cos(\theta + 2\,\pi\,n) \tag{32}$$

which if written as

$$\cosh(j\,\theta) = \cosh(j\,\theta + 2\,\pi\,n\,j) \tag{33}$$

exactly as $$\cosh(\phi) = \cosh(\phi + 2\,\pi\,n\,j), \tag{34}$$

shows that the periodicity of circular angles is also imaginary that is, quadrature, because equation (33) is identically the same thing as equation (32) except that it is in hyperbolic garb.

5. j must not be ignored, so that the circular, that is, quadrature, angle may not be confused with the hyperbolic angle.

6. Meaning 270 deg.

7. Meaning 360 deg.

Physical Meaning of Sine and Cosine

Let (θ) be a complex angle, and let the value of the radius vector for $(+\theta)$ be R_1, and for $(-\theta)$ be R_2. The vector mean value of R_1 and R_2 is called the cosine of angle (θ): hyperbolic cosine, if (θ) is a real or in-phase angle; circular cosine, if (θ) is a quadrature angle.

The value of the radius vector for $(+\theta)$ is $\epsilon^{+\theta}$, and for $(-\theta)$ it is $\epsilon^{-\theta}$, and the mean value of the two gives the cosine, as

$$\cosh(\theta) = \frac{R_1 + R_2}{2} = \frac{\epsilon^{+\theta} + \epsilon^{-\theta}}{2} \tag{35}$$

We prefer to write "cosh," instead of "cos," because we are treating the hyperbolic angle as real or linear, and the circular angle as quadrature, as this view is much more natural.

The foregoing formula agrees with the usual geometric representation of the cosine of a circular angle as the projection of the radius vector on the X = axis as shown in Fig. 11.[8]

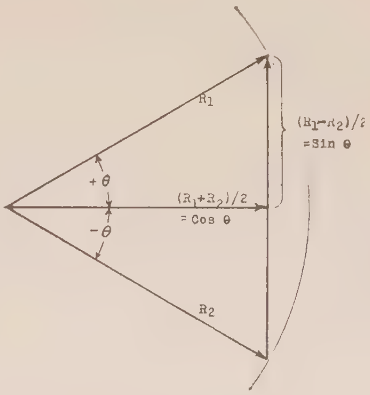

Fig. 11

For circular angles the numerical value and projection of the radius vector is the same for $(-\theta)$ as for $(+\theta)$, and therefore the definition of the cosine could be given either way, as mean sum or as projection, but not so with the hyperbolic functions. Assuming (θ) as an in-phase angle, $\epsilon^{+\theta}$ and $\epsilon^{-\theta}$ are not equal in magnitude neither are their projections, for their projections are identical with themselves. We could, therefore, define a cosine, if we pleased, either as the mean projection or as the (vectorial) mean value of the radius vector for $(+\theta)$ and $(-\theta)$. The cosine then may be looked upon as a vector parallel to the mean radius vector, as is clear from Figs. 11 and 12.

Turning to the sine of (θ), it is the mean (vector)

8. This vectorial point of view is the physical basis of the treatment of a harmonic flux as the resultant of two constant fluxes rotating in opposite directions in single-phase induction motors, as will be better evident in section on "Characteristics of Sines."

difference of the radius vector for $(+\theta)$ and $(-\theta)$. Thus,

$$\sinh(\theta) = \frac{R_1 - R_2}{2} = \frac{\epsilon^{+\theta} - \epsilon^{-\theta}}{2} \tag{36}$$

If (θ) is a real angle, the sine is hyperbolic, if a quadrature angle, the sine is circular.

The idea of projection does not hold very well for the sine of both trigonometric and hyperbolic angles without undue straining, but the idea of "one half vector sum" for cosine, and "one half vector difference" for sine, holds equally for circular as well as for hyperbolic angles.

For a hyperbolic angle, the sine is a vector in phase with the radius vector; but for a circular angle, the sine is perpendicular to the mean radius vector as will

Fig. 12

be seen from Figs. 11 and 12. From this it follows that, if θ is an in-phase or hyperbolic angle,

$$\sinh(j\,\theta) = j\sin(\theta) \tag{37}$$

whereas

$$\cosh(j\,\theta) = \cos(\theta) \tag{38}$$

Other trigonometric functions need not be considered here, because they can all be expressed in terms of sines and cosines.

Graphical Construction

Graphical constructions for the sines and cosines of complex angles follow at once from their definitions as the mean sum or mean difference of the radius vector for the plus and minus angle, and from the graphical construction for the radius vector of a complex angle. The framework of Fig. 10 is used for this purpose. Given the complex angle $(\theta_1 + j\,\theta_2)$; the radius vector R_1 for plus $(\theta_1 + j\,\theta_2)$, and the radius vector R_2 for minus $(\theta_1 + j\,\theta_2)$ are located. Then, half their vector sum and difference give the trigonometric functions:

$$\cosh(\theta_1 + j\,\theta_2) = \frac{R_1 + R_2}{2} \tag{39}$$

$$\sinh(\theta_1 + j\,\theta_2) = \frac{R_1 - R_2}{2} \tag{40}$$

The addition and subtraction of R_1 and R_2 are carried out vectorially as shown in Fig. 10. Calculated analytically, we have

$$\cosh(\theta_1 + j\,\theta_2) = \frac{\epsilon^{+\theta_1}}{2}(\cos\theta_2 + j\sin\theta_2) + \frac{\epsilon^{-\theta_1}}{2}(\cos\theta_2 - j\sin\theta_2) \tag{41}$$

$$\sinh(\theta_1 + j\,\theta_2) = \frac{\epsilon^{\theta_1}}{2}(\cos\theta_2 + j\sin\theta_2) + \frac{\epsilon^{-\theta_1}}{2}(\cos\theta_2 - j\sin\theta_2) \tag{42}$$

Characteristics of Sines and Cosines

The graphical constructions for the trigonometric functions give a true physical picture but can not naturally fully convey the various characteristics of these functions at sight. The solution of many physical problems involves differential equations, that is, requires a knowledge of the "rate of change" characteristics of functions. We may therefore analyze such characteristics of the radius vector as it traces circular or hyperbolic or complex angles to see how and why sines and cosines of these angles come in.

If a quantity is varying at a constant percentage, its absolute rate of change is proportional to itself. If the function is increasing, its rate of change, that is, its velocity, is positive; if decreasing, its velocity is negative; if rotating without change of length, its velocity is j, that is, quadrature; and, if both rotating and changing in length, its velocity is general or complex. If the rate of change or velocity is proportional to the quantity, the rate of change of the rate of change, that is, the rate of change of the velocity, or, in other words, the acceleration, is also proportional to the quantity. If the velocity is in-phase, the acceleration is also in-phase and has the same direction as the original quantity, regardless of whether the quantity is increasing or decreasing. If the velocity is in quadrature, the acceleration is in quadrature with the velocity and thus negative with respect to the original quantity. Thus, if a quantity is rotating, (*i. e.*, varying at a constant quadrature percentage of itself at every point), its acceleration is proportional to itself but negative, regardless of whether it is rotating positively or negatively, that is, clockwise or counter-clockwise. If then, we know by any physical consideration that the acceleration of a quantity R is proportional to itself and has the same sign as itself, it must be either a positively rotating quantity (equation **43**); or a negatively rotating quantity (equation **44**); or the resultant of two quantities rotating in opposite directions (equations **45** and **46**), that is, a harmonic quantity. Conversely, a harmonic quantity may be considered as the resultant of two constant vector components rotating in opposite directions as is assumed in the theory of the single-phase induction motor.

$$R = A\,\epsilon^{+jwt} \tag{43}$$

or

$$= A\,\epsilon^{-jwt} \tag{44}$$

or

$$= A\,(\epsilon^{+jwt} + \epsilon^{-jwt}) = 2\,A\cos(w\,t) \tag{45}$$

or

$$= A\,(\epsilon^{+jwt} - \epsilon^{-jwt}) = 2\,A\sin(w\,t) \tag{46}$$

From this it follows that the sine and the cosine functions are more general than the simple exponential functions, and include the common characteristics of both the increasing and the decreasing exponentials. This applies to the hyperbolic functions as well as to the circular. Thus, if the acceleration of the quantity

R is proportional to itself and in the same direction, then, the equation of the quantity is of the form.

$$R = A\,\epsilon^{+wt} \quad (47)$$

or $$= A\,\epsilon^{-wt} \quad (48)$$

or $$= A\,(\epsilon^{+wt} + \epsilon^{-wt}) = 2\,A \cosh(w\,t) \quad (49)$$

or $$= A\,(\epsilon^{+wt} - \epsilon^{-wt}) = 2\,A \sinh(w\,t) \quad (50)$$

Thus, again, the sine and cosine functions are more general than the simple exponential, and include the acceleration characteristics of both the increasing and the decreasing exponential.

Just as the trigonometric functions can be compounded from the simple exponentials, so, the simple exponentials can be given in terms of the trigonometric functions. Thus,

$$\epsilon^{\pm wt} = \cosh(w\,t) \pm \sinh(w\,t) \quad (51)$$

$$\epsilon^{\pm jwt} = \cos(w\,t) \pm j \sin(w\,t) \quad (52)$$

In these equations, the exponential form is of course to be preferred to the trigonometric form on account of its simplicity.

The application of the characteristics of sines and cosines may be illustrated by a few familiar examples:

An object is displaced against an elastic force which varies directly with the displacement but is directed opposite to it. If the body is released, the force accelerates it and since the force and therefore the acceleration are proportional to the displacement but opposite to it, the motion will be like a circular sine or cosine function, that is, harmonic.

A condenser is discharged through an inductance. The rate of change of the current produces voltage across the inductance equal and opposite to that of the condenser. That is, the condenser voltage is proportional and opposite to the rate of change of the current. However, a condenser current is proportional to the rate of change of the condenser voltage, and since the condenser voltage is proportional (but negative) to the rate of change of the current, the rate of change of the condenser voltage and, hence, the current are proportional to the acceleration of the current. Thus, the current and its acceleration are proportional to each other and opposed, and therefore the current is a circular sine or cosine function, that is, harmonic.

A leaky transmission line is carrying current. Assume it direct current for simplicity. As we advance along the line the current will become less and less, due to leakage to ground. The rate at which the line current is changing is equal to the leakage current, and this rate is negative because the current is decreasing. The rate at which the leakage current changes along the line is proportional to the line current and is negative with respect to it in its turn because the leakage current also decreases. Thus the line current and its second rate of change are proportional to each other and have the same sign, and therefore, the distribution of current along the line must be like a hyperbolic sine or cosine.

Analytically,

If $$\frac{d^2\,y}{d\,t^2} = +\,w^2\,y, \text{ then,}$$

$$\begin{aligned} y &= A \sinh(w\,t), \text{ or,} \\ &= B \cosh(w\,t), \text{ or their combination} \end{aligned}$$

If $$\frac{d^2\,y}{d\,t^2} = -\,w^2\,y, \text{ then,}$$

$$\begin{aligned} y &= A \sin(w\,t), \text{ or,} \\ &= B \cos(w\,t), \text{ or their combination} \end{aligned}$$

And, if, $$\frac{d^2\,y}{d\,t^2} = (w_1 + j\,w_2)^2\,y, \text{ then,}$$

$$\begin{aligned} y &= A \sinh(w_1 + j\,w_2)\,t, \text{ or} \\ &= B \cosh(w_1 + j\,w_2)\,t, \text{ or} \\ &= C \sin(j\,w_1 - w_2)\,t, \text{ or} \\ &= D \cos(j\,w_1 - w_2)\,t. \end{aligned}$$

These solutions are of course the simpler solutions, and still more general solutions are obtained by combining the simpler solutions, but that is another subject.

Complex Angles in Space

All the foregoing discussions were limited to a plane and one little difficulty was encountered in having the quadrature component of a vector angle a curve instead of a straight line, which was partially excused on the ground that if the arc was taken short enough it would be straight. The reason why the arc as a vector could not be represented by its chord was stated to be due to the fact that any finite chord could not be perpendicular to the radius vector at every point along that chord. In other words, the arc was curved with respect to the X-axis but straight with respect to the rotating radius vector, having a constant angle with respect to it at every position, for what is the fundamental definition of a straight line (in terms of differential equations) if not this, that its slope (therefore angle) is constant? The argument is admittedly a trifle strained; the reason is that it is limited to a plane. However, if we take a three-dimensional view of the matter, these arguments become unnecessary, for we then find that the quadrature angle is really to be represented by the axis of the arc. It then is easy to see that no matter how curved the arc, its axis will be straight. In plane analysis, however, there is no room for an axis, the third dimension being barred, and therefore the arc itself is taken to represent the angle. Representing the quadrature (circular) angle by the axis of the arc does not alter the fact that the circular and hyperbolic angle will be at right angles with each other, because hyperbolic angle will still be represented by the component of the path parallel to the radius vector, and, therefore, the axis of the quadrature component perpendicular to the plane of the path will

also be perpendicular to the in-phase component of the path.

In treatises on vector analysis it is shown that the product, or quotient, of two vectors in quadrature is another vector and is perpendicular to the plane of the two factors. Referring now to Fig. 3, the elementary circular angle is

$$d\,\theta_2 = \frac{d\,R_2}{R}$$

which is the quotient of two vectors in quadrature, and is therefore, a vector perpendicular to the plane of $(d\,R_2)$ and R. Of course, it is difficult to show this normal in a flat diagram and therefore it is rotated into the plane of the diagram to make it visible, in which case it coincides with the circular arc, not with its chord. That is, when $d\,R_2/R$ is represented by $(d\,R_2)$, it is equivalent to rotating the normal through 90 deg. around the radius vector as axis into the plane of $(d\,R_2)$ and (R) in infinitesimal steps.

Considering now the elementary hyperbolic angle,

$$d\,\theta_1 = \frac{d\,R_1}{R} \qquad \text{Fig. 3.}$$

This is the quotient of two parallel vectors, and is therefore a scalar. In order that the representation may be consistent and show the true relationship between the two kinds of angles, if the circular angle is multiplied by (R) so must the hyperbolic angle be multiplied by R. The result is that this multiplication by R rotates the vector circular angle into the plane of the diagram and identifies it with the circular arc $d\,R_2$, and changes the scalar hyperbolic angle into vector and identifies it with the radial vector component $d\,R_1$ of the path in-phase with the radius vector. Looking at this from another point of view, if we are interested in showing the relationship of circular and hyperbolic angles, then,

$$\frac{d\,R_1}{R} : \frac{d\,R_2}{R} = d\,R_1 : d\,R_2$$

Hence, the representation of the circular and hyperbolic angles by the vectors $d\,R_2$ and $d\,R_1$ is justified.

It may be evident from the foregoing critical analysis that a complex angle is a vector in the same sense and limitation as an impedance; the per cent resistance component of an impedance corresponding to the hyperbolic angle, the per cent reactance component to the circular angle. In fact, the per cent vector impedance of a circuit is the complex angle of the circuit in radians. Strictly, of course, the percentage must be compound percentage not simple percentage. However, in small percentages, the distinction is negligible. When the percentages are large, or when the circuit has distributed constants the distinction can not be ignored.

If the radius vector traces a three dimensional curve, the quadrature component of the path may be in any one of an infinite number of planes and its determination requires two mutually perpendicular vectors in quadrature with the radius vector, of the form,

$$\theta = \theta_0 + j_1\,\theta_1 + j_2\,\theta_2$$

where j_1 and j_2 are the two reference vectors. As electrical problems are as a rule in one plane, and those which are three-dimensional have such symmetry that they can be treated as problems in one plane, the three dimensional complex angle has little application for the engineer. However, it has been mentioned above to indicate that the physical interpretation developed in this paper covers even this more generalized angle, and for the guidance of those who may wish to make a more extended study of the subject.

NEW GLOSSARY OF ELECTRICAL TERMS

The Bureau of Foreign and Domestic Commerce announces a revised edition of the Glossary of Electrical Terms, which has been compiled by the Electrical Equipment Division in cooperation with the Electrical Manufacturers' Council. The new glossary has been prepared to conform to changes in the export classification schedule, which went into effect on January 1, 1923, and should be used by every exporter of electrical materials in the preparation of his export declaration.

This pamphlet is intended solely for reference purposes by exporters when making out their export declarations, so that these will indicate accurately the goods shipped, in so far as statistical classifications are concerned. There is apparently some uncertainty in the minds of exporters as to the use of these declarations and attempt is made often to make them conform exactly with invoices. That is not necessary. The desire is merely to have the data sufficiently clear so that the goods may be definitely listed as belonging to some one of the clearly defined export classifications, the actual class number given in the glossary being indicated.

Copies of the new glossary may be obtained from the Superintendent of Documents, Government Printing Office, Washington, D. C., or from the district offices of the Bureau of Foreign and Domestic Commerce.

TO RESTORE A LIGHTING SYSTEM

1. Wash reflectors and lamps thoroughly with soap and water at least every third or fourth cleaning period.
2. Fill empty sockets and replace burned-out and blackened lamps with new ones of the correct size and proper voltage rating. The voltage rating of the lamp should be at least no higher than the voltage at the socket when the system is in use. Avail yourself of the service of the lamp manufacturer in determining what the voltage rating of your lamp should be.
3. Refinish ceiling and high side walls in white or in a very light cream color.
4. Make some reliable employe responsible for the maintenance of the lighting system and give him sufficient authority to enable him to get the work done.

The Apparent Dielectric Strength of Cables

BY ROBERT J. WISEMAN

Member A. I. E. E.
The Okonite Company, Passaic, N. J.

AFTER reading with considerable interest, the two papers presented at the annual convention of the Institute, dealing with the dielectric strength of cables[1], the writer analyzed the data presented in each paper from an entirely different viewpoint and also the data given in each paper according to the views of the other paper.

The results obtained were quite interesting and are given below, so that the members of the Institute may be in a position to criticize the new viewpoint. Perhaps from all the views which have been given, we may be able finally to arrive at a complete understanding of what dielectric strength as applied to cables actually is.

We are all familiar with the formula which expresses mathematically the dielectric stress at any point in the insulation surrounding a round conductor when a voltage is applied between the conductor and sheath, namely:

$$K = \frac{0.434\, V}{x \log_{10} R/r}$$

where K is the dielectric stress at a distance x from the center of the conductor; V is the voltage between conductor and sheath; R the radius of the dielectric; and r the conductor radius.

Likewise we are all familiar with the fact that the maximum stress occurs at the surface of the conductor and the minimum stress at the surface of the dielectric. Again, as the diameter of the conductor is varied and the diameter of dielectric held constant, the computed value of K reaches a minimum value when the conductor diameter is $D/2.72$. This has been very clearly described in the Middleton, Dawes and Davis paper.

For a long while we have considered the maximum stress theory as described by Russell[2] as the proper one to use, but when we compute the maximum value of K from actual experimental data we observe quite a large variation in K maximum, when it should be constant. Osborne[3] presented a needle-point theory to explain the departure of practise from theory.

In 1914, Messrs. Middleton and Dawes[4] presented a paper before the Institute, in which they substituted an empirical formula for the logarithmic formula when expressing the breakdown strength of cables when the ratio R/r is greater than 2.72. Their present paper is a further analysis of the problem from the same viewpoint.

There seems to be a contradiction in their paper. According to the views expressed when developing their empirical law, they assume a fixed value of maximum stress and analyze their data with this in view. Later in the paper, they discuss the variation of the maximum stress with the ratio R/r. The empirical law should be corrected to bring in the change in maximum stress with the ratio R/r.

Simons takes the data which Fernie[5] published in 1921 and tends to disapprove his theory, showing that taking Fernie's data, the average stress theory is just as good.

Fundamentally, there seems to be no foundation for the average stress theory, as it implies that at the moment of breakdown the stress is a function only of the thickness of dielectric. From the nature of the shape of the electrostatic field in a single-conductor cable, experimental data, as well as the theoretical formula, we know this is not so.

The minimum stress theory is an interesting endeavor to find a formula by means of which the breakdown strength of cables may be computed when designing cables. It takes into account the shape of the electrostatic field—which is good. However, taking into consideration our ideas as to what the dielectric strength[6] of a dielectric is and knowing that we have a higher stress in the body of the dielectric at the moment

1. "Potential Gradient in Cables," by W. I. Middleton, C. L. Dawes and E. W. Davis.

"On the Minimum Stress Theory of Cable Breakdowns," by D. M. Simons.

2. "Dielectric Strength of Insulating Materials and the Grading of Cables," by A. Russell, *Journal* I. E. E., Vol. 40, page 6, 1907.

3. "Potential Stresses in Dielectrics," by H. S. Osborne, TRANS. A. I. E. E., Vol. XXIX, page 1553, 1910.

To be presented at the Midwinter Convention of the A. I. E. E., New York, N. Y., February 14-17, 1923.

4. "Voltage Testing of Cables," by W. I. Middleton & C. L. Dawes, TRANS. A. I. E. E., Vol. 33, page 1185, 1914.

5. "Insulating Materials," by Fernie, Beama, page 244, 1921.

6. Osborne quotes very nicely from Maxwell on this point:

"If the electromotive intensity at any point in a dielectric is gradually increased, a limit is at length reached at which there is a sudden electrical discharge through the dielectric. The electromotive intensity when this takes place is a measure of what we may call the electric strength of the dielectric."

Osborne then writes:

"This critical value of the electric intensity in a dielectric is itself called, in common parlance, the electric strength of the dielectric.

Granting the existence of this definite physical constant, the electric strength of a dielectric that is, a definite value of electric intensity which cannot be continuously or repeatedly exceeded without disrupting the dielectric, the voltage required to break down a given design of insulation depends evidently upon two factors:

1. The electric strength of the dielectric.
2. The distribution of the electric intensity, or as one may now call it, the electric stress, in the dielectric."

of breakdown than the stress at the surface of the dielectric, it seems hard to support the minimum stress theory.

In all the theories which have been advanced so far, it has been assumed that the dielectric strength of the dielectric in a cable is a constant and independent of the shape of the electrodes after taking into account the shape of the electrostatic field for computing the dielectric strength from the theoretical law. Why is it not fair to assume that the dielectric strength as computed is not what we commonly called the "true dielectric strength" of the dielectric but really the "apparent dielectric strength?" That is, we mean the true dielectric strength must be corrected for the shape and size of the electrodes and that this correction factor will give us a means of obtaining a constant which we can call the true dielectric strength of the dielectric.

There are grounds for making the above assumption. We know that if a dielectric is tested for breakdown strength between parallel plates, it is necessary to state the size of the electrodes and the thickness of the dielectric or the results are not of great value. Mr. F. M. Farmer[7] in a very valuable paper shows this to be true. The writer believes from tests he has conducted that the dielectric strength of a dielectric when tested between parallel plates is a constant, provided a correction factor is used. Here again it is a question of true or apparent dielectric strength. This correction factor is very nearly the correction factor for the increase in capacity between two parallel plates due to end effect.

Knowing that the dielectric strength for parallel plates is a function of the area and thickness of dielectric, suppose we assume that the dielectric strength of a cable is a function of the *radii* or surface of the conductor and sheath.

The writer, in 1914 and 1915, conducted a research[8] on the present problem. The same methods were used as described in the Middleton, Dawes and Davis paper, that is, samples of cables were studied with constant conductor diameter and variable sheath diameter and variable conductor diameter with a constant sheath diameter. Instead of using the commercial kind of dielectric, ceresine wax was used, as it is more homogeneous than rubber, paper or varnished cambric, could be obtained free of impurities and absorbs practically no moisture.

It was possible to explain the results obtained by means of ionization. Although a great many investigators do not believe in free ions in solids, if we assume they do exist and then apply the laws of ionization, it is remarkable how well computed results agree with experimental data. If we take the law of corona for air about a wire and apply it to a solid insulation (with the proper constants), we can express the dielectric stress at the surface of a conductor in a cable in a form which will give good agreement between computed and experimental values. This corona law is:

$$K = K_0 \left(1 + \frac{a}{\sqrt{r}}\right)$$

where r is the radius of the conductor, a is a constant, K_0 is the true dielectric strength of the dielectric, and K is the apparent dielectric strength of the dielectric. K is the value which should be used when computing the breakdown voltage of a cable having a conductor radius r.

At the time of the research, the writer had only his own data to study and, consequently, was only able to apply the ionization theory to his data. Since the publication of the recent papers, a further study has been made along the lines described above and the empirical law

$$K = K_0 \left(1 + \frac{a}{\sqrt{r}}\right) \sqrt{R}$$

has been found to express the value of K in the cable formula

$$V = K\, r \ln R/r$$

This formula for maximum stress states that the dielectric strength of a dielectric in a cable is a function of the radii of the conductor and insulation. If we hold the radius of the conductor r constant and increase the radius of insulation R, K will increase on account of the term $\sqrt{R}$. If we hold the radius of insulation constant and decrease the conductor radius, K will increase. We know from data presented that this is so.

If we should plot $K/\sqrt{R}$ as ordinates against $1/\sqrt{r}$ as abscissas, the value of $K/\sqrt{R}$ for various values of $1/\sqrt{r}$ should fall along a straight line.

Let us now compare the four different viewpoints, namely, the minimum stress, the average stress, the increase in conductor diameter theory when $R/r > 2.72$ and the ionization theory.

Table I gives the value of dielectric strength computed for each viewpoint for the data given in Table II of Fernie's paper. The minimum stress seems to apply very well, considering experimental data. The average stress, although giving a good average deviation from an average stress value, does not seem to apply, as the average stress is decreasing with a decrease in the ratio R/r, whereas it should be independent of ratio R/r. For the ionization theory, the equation for K maximum was found by plotting $K/\sqrt{R}$ against $1/\sqrt{r}$ to be

$$K \text{ maximum} = 131.6 \left(\frac{1.935}{\sqrt{r}} - 1\right) \sqrt{R} \text{ kv. per cm.}$$

Taking this formula, the value of K maximum was calculated with the results given in column 7. A comparison of columns 6 and 7 gives an idea of the

7. "Dielectric Strength of Thin Insulating Materials," by F. M. Farmer, TRANS. A. I. E. E., Vol. 32, page 2097, 1913.

8. "A Study of the Dielectric Strength of Cables," by R. J. Wiseman, Thesis, Electrical Engineering Department, Massachusetts Institute of Technology, June 1915.

TABLE I

DATA TAKEN FROM FERNIE, TABLE II.

R mm.	r mm.	t mm.	R/r	Break down Voltage kv./cm.	K max. Actual kv./cm.	K max. Calc. kv./cm.	Per cent Diff.	K min. kv./cm.	K aver. kv./cm.	$K_1 = \frac{5.44\ V}{D}$
11.32	2.43	8.89	4.65	160	428	410	− 4.2	92.0	180	384
17.97	5.27	12.70	3.41	217	335	295	− 11.9	98.3	171	328
12.59	3.69	8.89	3.40	130	288	338	+ 17.3	84.3	146	260
14.16	5.27	8.89	2.69	134	257	262	+ 1.9	95.6	151	
16.26	7.37	8.89	2.21	140	240	212	− 11.7	108.7	158	
11.62	5.27	6.35	2.21	91.5	219	237	+ 8.2	99.5	144	
17.06	8.17	8.89	2.09	114	189	198	+ 4.8	90.6	128	

Average Diff. 8.6 per cent (Col. 8)

Average Dev. 5.9 per cent (Col. 9)
8.7 per cent (Col. 10)

$$K \text{ maximum} = 131.6 \left(\frac{1.935}{\sqrt{r}} - 1 \right) \sqrt{R} \text{ kv. per cm.}$$

TABLE II

DATA TAKEN FROM FERNIE, TABLE III.

R mm.	r mm.	t mm.	R/r	Break down Voltage kv./cm.	K max. Actual kv./cm.	K max. Calc. kv./cm.	Per cent Diff.	K min. kv./cm.	K aver. kv./cm.	$K_1 = \frac{5.44\ V}{D}$
7	2	5	3.50	54.3	216	214	− 0.9	61.8	109	211
9	3	6	3.00	69.0	209	191	− 8.6	69.7	115	208
11	4	7	2.75	65.3	161	176	+ 9.3	58.6	93	162
13	5	8	2.60	83.9	175	168	− 4.0	67.5	105	
16	6	10	2.67	94.2	160	165	+ 3.1	60.1	94	

Average Diff. 5.2 per cent (Col. 8)

Average Dev. 6.4 per cent (Col. 9)
7.6 per cent (Col. 10)

$$K \text{ maximum} = 40.0 \left(\frac{3.29}{\sqrt{r}} - 1 \right) \sqrt{R} \text{ kv. per cm.}$$

agreement between K maximum actual and K maximum calculated, assuming the corona law to hold. The average difference between K maximum actual and K maximum calculated is 8.6 per cent, which compares favorably with the average deviations of minimum stress and average stress. The Middleton theory gives less values for K_1 than K maximum, as computed from the formula. The stress is not constant, decreasing with a decrease in ratio R/r.

Table II contains an analysis of the various views for the data given in Table III of Fernie's paper. Both the minimum and average stress theories apply well here. The Middleton theory again gives decreasing values of stress with a decrease in ratio R/r. Attention is directed to the very close agreement of K maximum actual and K computed from $K_1 = 5.44\ V/D$. The equation for K maximum for ionization theory is

$$K \text{ maximum} = 40.0 \left(\frac{3.29}{\sqrt{r}} - 1 \right) \sqrt{R} \text{ kv. per cm.}$$

Column 7 gives the calculated value of K maximum, using this equation. The average difference between Columns 6 and 7 is 5.2 per cent, which is slightly better than the average deviations for minimum stress and average stress.

Table III is a reproduction of Table I in the Middleton, Dawes and Davis paper. As in the case for the two previous tables, this table gives a comparison of the values of K for the different views. The minimum stress and average stress theories do not hold. The value of $K_1 = \dfrac{5.44\ V}{D}$ increases as the ratio R/r decreases. The samples tested had a constant diameter of insulation D. Therefore, we should expect a curve similar in shape to curve $A\ B\ C$ in Fig. 2 of their paper. Fig. 3 of their paper shows the points to be widely scattered and the curve lies between the theoretical curve as computed by the logarithmic law, and a curve similar to $A\ B\ C$ of Fig. 2. Although allowance must be made for deviations of points from true values, still it seems as if we should get better agreement than they present.

Turning now to the ionization theory, Column 7 gives the calculated value of stress after finding the equation

$$K \text{ maximum} = 710 \left(1 + \frac{0.1832}{\sqrt{r}} \right) \sqrt{R} \text{ volts per mil.}$$

Fig. 1 is a plot of K maximum$/\sqrt{R}$ against $1/\sqrt{r}$ to

show how the points fall along a straight line. This is given in order to compare with Fig. 11 of their paper which shows K maximum plotted against D/d as a straight line. Column 8 gives the per cent difference between columns 6 and 7. It shows a variation plus and minus and an average difference of 4.2 per cent, which is a good agreement for experimental data.

Table IV is the same as Table II of the Middleton, Dawes and Davis paper. The minimum stress theory does not hold. There is a constantly increasing value of average stress with decrease in ratio R/r but not of great amount. The average value is 243 volts per mil with a deviation from the average of 6.6 per cent. The authors in their paper state their empirical law, $K_1 = 5.44\ V/D$ does not hold. In this case K_1 decreases with a decrease in R/r. Column 7 gives the calculated value of maximum stress, using the formula

$$K \text{ maximum} = 149.2\left(\frac{2.02}{\sqrt{r}} - 1\right)\sqrt{R} \text{ volts per mil,}$$

which was obtained from the straight line plotted in Fig. 1 for K maximum$/\sqrt{R}$ against $1/\sqrt{r}$. Column 8 gives the per cent difference between columns 6 and 7. The average difference is 4.3 per cent, which is a good agreement and better than the average deviation for the average stress values.

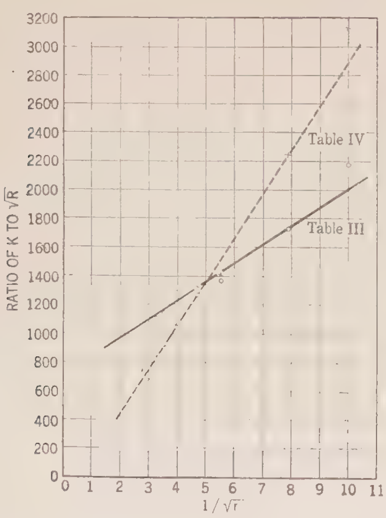

Fig. 1—Relation between Ratio of Conductor Stress to Square Root of Insulation Radius and Reciprocal of Square Root of Conductor Radius for Cables in Tables III and IV.

Table V is also taken from the Middleton, Dawes and Davis paper, Table III. The minimum stress and average stress theories do not hold. Instead of using $K_1 = 6.27\ V/D$ to compute the stress according to the author's views, the formula $K_1 = 5.44\ V/D$ was used. The factor 1.15 has already been used in the development of the formula. This will not detract from the nature of the study as it only gives different values of K_1 from those presented in their paper. K_1 given in the second last column shows reasonably consistent values with an average deviation from the average of 3.9 per cent. The last column gives the values of K maximum/$\sqrt{R}$. Here also we get reasonably consistent values with an average deviation from the average of 3.2 per cent or a shade better than 3.9 per cent It is a question as to which view to choose here. Column 7 gives the calculated value of stress after taking the average value of $K/\sqrt{R} = 3100$ and multiplying it by $\sqrt{R}$ for each point. In view of the small variation in $K/\sqrt{R}$ for each point from the average value, we should expect as good agreement in the calculated value of K maximum.

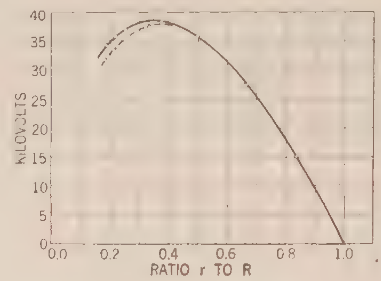

Fig. 2—Relation between Rupturing Voltage and the Ratio for Data in Table VI

The average difference between actual and calculated values of K maximum is 3.1 per cent, which is very close agreement.

The data in Table VI are taken from the thesis of the writer. Constant diameter over insulation and variable conductor diameter were used. The dielectric strength has been computed for the various viewpoints. Fig. 2 is a plot of V against r/R, taking as a value of K the average of the values of K for ratios $R/r < 2.72$ as was done by Middleton, Dawes and Davis for the data in their Table I. The actual curve for values of $R/r > 2.72$ or $r/R < 0.368$ is slightly higher than the theoretical and more nearly like the theoretical than should be expected according to the Middleton theory. Attention is drawn to the small variation in K maximum over the whole range of values of R/r from 1.198 to 5.35. It would be allowable to take an average of all values and the average deviation is only 2.9 per cent from the average. This is better than the results in any other table. The writer believes this slight change in dielectric strength is due to the greater homogeneity of the dielectric than for dielectrics used by others. It would be fair to state from the values given here that the dielectric strength is a constant and the theoretical law is correct. However, the fact that the dielectric strength decreases with a decrease in ratio R/r causes us to modify the above statement. While studying the data given in the table, the writer found the law $K = K_0\,(1 + a/\sqrt{r})$ to apply. It was found recently that the term "$\sqrt{R}$" would further improve the empirical equation for maximum value of dielectric

TABLE III
DATA TAKEN FROM MIDDLETON PAPER, TABLE I.
$D = 0.375$ in.

Size Cond.	r mils.	t mils.	R/r	Break down Voltage kv.	K max. Actual V/mil.	K max. Calc. V/mil.	Per cent Diff.	K min. V/mil.	K aver. V/mil.	$K_1 = \frac{5.44\ V}{D}$ V/mil.
24 sol.	10.0	178	18.65	27.7	942	868	− 7.9	50	156	402
20	16.0	172	11.70	29.5	748	751	+ 0.3	64	171	428
14	32.5	155	5.77	33.9	592	619	+ 4.6	103	219	492
	45.0	142.5	4.17	35.3	549	572	+ 4.2	132	248	512
8	64.0	123.5	2.93	39.1	568	529	− 6.7	194	317	568
6	81.0	106.5	2.31	33.5	493	505	+ 2.4	213	315	
5	93.0	94.5	2.02	31.8	487	492	+ 1.1	242	336	
2	129.0	58.5	1.45	23.8	494	463	− 6.3	340	407	
3 str.	130.0	57.5	1.44	28.0	587			407	487	

Average Diff. 4.2 per cent (Col. 8)

$$K \text{ maximum} = 710 \left(1 + \frac{0.1832}{\sqrt{r}}\right) \sqrt{R} \text{ volts per mil.}$$

(r and R in inches)

TABLE IV
DATA TAKEN FROM MIDDLETON PAPER, TABLE II.
$D = 0.375$ in.

Size Cond.	r mils.	t mils.	R/r	Break down Voltage kv.	K max. Actual V/mil.	K max. Calc. V/mil.	Per cent Diff.	K min. V/mil.	K aver. V/mil.	$K_1 = \frac{5.44\ V}{D}$ V/mil.
24 sol.	10.0	178	18.65	39.9	1355	1240	− 8.4	72.6	224	580
20	16.0	172	11.70	38.3	971	968	− 0.3	82.9	223	556
14	32.5	155	5.77	34.9	612	660	+ 7.7	107.0	225	508
	45.0	142.5	4.17	36.8	571	552	− 3.3	137.0	258	535
8	64.0	123.5	2.93	31.6	460	452	− 1.8	157.0	256	459
6	81.0	106.5	2.31	26.9	395	395	+ 0.0	171.0	253	
5	93.0	94.5	2.02	24.0	368	364	− 1.0	183.0	254	
3	114.5	73.0	1.637	16.8	297	322	+ 8.3	181.0	230	
2	129.0	58.5	1.453	15.7	326	299	− 8.3	224.0	268	

Average Diff. 4.3 per cent (Col. 8)
Average K aver. V/mil. 243. (Col. 10)
Average Dev. 6.6 per cent (Col. 10)

$$K \text{ maximum} = 149.2 \left(\frac{2.02}{\sqrt{r}} - 1\right) \sqrt{R} \text{ volts per mil.}$$

(r and R in inches.)

TABLE V
DATA TAKEN FROM MIDDLETON PAPER, TABLE III
$d = 20.1$ mils.

D ins.	R ins.	t mils.	R/r	Break down Voltage kv.	K max. Actual V/mil.	K max. Calc. V/mil.	Per cent Diff.	K min. V/mil.	K aver. V/mil.	$K_1 = \frac{5.44\ V}{D}$	$K/\sqrt{R}$
0.0938	0.0469	26.8	4.69	9.93	643	670	+ 4.2	137	370	583	2980
0.125	0.0625	42.4	6.22	13.6	744	775	+ 4.0	119.5	321	591	2970
0.1563	0.0782	58.1	7.77	17.8	870	867	− 0.3	112	306	620	3110
0.1875	0.0938	73.7	9.33	23.0	1026	950	− 7.4	110	312	668	3350
0.250	0.1250	104.9	12.45	27.3	1083	1094	+ 0.8	87	260	595	3060
0.3125	0.1563	136.2	15.55	34.2	1244	1224	− 1.6	80	251	596	3150
									Average:	609	3100

Average Diff. 3.1 per cent (Col. 8)
Maximum Dev. + 9.7 per cent (Col. 11)
+ 8.1 per cent (Col. 12)
Minimum Dev. − 4.3 per cent (Col. 11)
− 4.2 per cent (Col. 12)
Average Dev. 3.9 per cent (Col. 11)
3.2 per cent (Col. 12)

strength. Column 6 gives the calculated value of maximum stress from

$$K \text{ maximum} = 281\left(1 + \frac{0.0546}{\sqrt{r}}\right)\sqrt{R} \text{ kv. per cm.}$$

Very close agreement is obtained with the actual value of maximum stress as given in column 5, and the average difference between actual and calculated values is only 0.9 per cent. The minimum stress and average stress theories do not hold.

The writer also conducted tests with a constant diameter of conducter ($2\,r$) and variable diameter ($2\,R$) the geometry of the cable, for example, with d, D or D/d. This is necessary, as in its present form the formula cannot be used to determine beforehand the breakdown voltage of a cable, unless previous data had been obtained for the cable.

The ionization theory has been applied satisfactorily to all the data available. Two assumptions were made in developing the theory; first, ionization takes place in a solid dielectric and the dielectric should follow the laws of ionization; and, second, the dielectric strength of a dielectric is a function of the size and shape of the electrodes, in the case of cables it being found a function of the square root of the radius of the dielectric.

TABLE VI.
$D = 0.952$ cm.

r cm.	t cm.	R/r	Break down Voltage kv.	K max. Actual kv./cm.	K max. Calc. kv./cm.	Per cent Diff.	K min. kv./cm.	K aver. kv./cm.	$K_1 = \frac{5.44\ V}{D}$ kv./cm.
0.0891	0.387	5.35	34.3	230	229	−0.4	21.4	88.6	196
0.1024	0.374	4.65	35.8	228	227	0.4	24.5	96.0	205
0.1194	0.357	3.99	37.0	224	224	0.0	28.1	104	211
0.1588	0.317	3.00	37.3	214	220	+2.8	35.7	118	213
0.179	0.297	2.66	38.5	220	219	−0.5	43.3	130	
0.238	0.239	2.00	35.9	218	215	−1.4	54.5	150	
0.318	0.1585	1.50	27.3	212	212	0.0	71.5	172	
0.398	0.0785	1.198	15.0	208	211	+1.4	87.0	191	

Average: 219
Average Diff. 0.9 per cent (Col. 7)
Max. Dev. +5.0 per cent (Col. 5)
Min. Dev. −5.0 per cent (Col. 5)
Average Dev. 2.9 per cent (Col. 5)

$$K \text{ maximum} = 281\left(1 + \frac{0.0546}{\sqrt{r}}\right)\sqrt{R} \text{ kv. per cm.}$$

over insulation. The results are not given here because the values of maximum dielectric strength decreased with increase in ratio R/r and none of the previously expressed views were applicable.

Considering the data which have been presented, it does not seem possible to state that the minimum stress theory and the average stress theory will explain the difference between experimental and computed values of voltage breakdown of a dielectric when used in a cable.

The empirical law, which states that the voltage breakdown is a function of the diameter over the insulation when the ratio of diameter over insulation to a conductor diameter is greater than 2.72 and that the dielectric within a diameter the value of which is $D/2.72$ does not add to the insulating properties of the conductor, seems to have some foundation. Further investigation along this line is desirable and in conjunction with the investigation the writer suggests a study be made of the variation of $K_1 = \frac{5.44\ V}{D}$ with

The law $K_1 = 5.44\ V/D$ is limited in its application to cables having ratios of R/r greater than 2.72.

The law $V = K_0\left(1 + \frac{a}{\sqrt{r}}\right)\sqrt{R}\ r \log R/r$ is applicable to all ratios as shown very clearly in the tables. It may therefore be considered as a more general formula than $K_1 = 5.44\ V/D$. The term $r \log R/r$ of the mathematically developed law is retained which is the term involving the shape of the electrostatic field.

What has been considered the dielectric strength of the dielectric is not the "true dielectric strength" as was supposed, but an "apparent dielectric strength" which is a function of the radii of the conductor and insulation, as was originally assumed.

This new viewpoint is given with the hope that others may consider it in connection with any data they may have and perhaps in time, from the various viewpoints, a correct understanding of what we mean by the "dielectric strength of a cable" will be found.

Applications and Limitations of Thermocouples for Measuring Temperatures

BY IRVING B. SMITH

Member, A. I. E. E.

Leads & Northrup Co., Philadelphia, Pa.

THE increasing application of temperature measurements to central station control arises primarily from the fact that the limiting factor of safe operation is temperature rather than current or energy output. Another and closely related factor is that of efficiency. With these two influences bearing upon the management there is demanded a knowledge of temperature conditions in the boiler, the engine, the generator and the distributing system. Hence the wide range of temperatures to be measured and the varying circumstances under which they are made often place them beyond the capacity of mercurial or other expansion types of thermometers. Moreover, a permanent and continuous record of temperature may be necessary or it may be desirable to automatically control or limit the temperature of some apparatus or process. The thermocouple has definitely established itself as a convenient and precise instrument for such purposes. We wish, therefore, to consider some of the difficulties to be overcome and precautions to be taken in applying the thermocouple to such measurements.

From the viewpoint of the station engineer we may conveniently classify temperature measurements under the following heads:

1. Feed Water
2. Boiler Water
3. Economizer
4. Flue Gas
5. Superheated Steam
6. Bearings
7. Generator Windings
8. Transformer Windings
9. Cables

Before considering these applications it is desirable to refer briefly to the sources of error that may arise in making temperature measurements with the thermocouple. They may be outlined as residing in the following:

1. Thermocouple Calibration
2. Instrument Calibration
3. Thermocouple Circuit
4. Radiation Losses
5. Conduction Losses
6. Parasitic e. m. f.
7. Temperature Lag
8. Cold Junction Temperature
9. Measured Temperature Variable
10. Measured Temperature Not Representative.

To be presented at the Midwinter Convention of the A. I. E. E New York, February 14-17, 1923.

I. Thermocouple Calibration

A thermocouple may be in error because its original calibration was wrong or because its calibration may have changed from use. Manufacturers are accustomed to furnish thermocouples with either a table or a curve giving the relation between e. m. f. and temperature. It is not safe to employ such couples or to secure wires and make up couples without either the manufacturer's or one's own check on the calibration. This applies particularly to base metal couples but it should not be ignored even with noble metal couples. The writer received some reports recently on checks of *Pt-Pt Rh* couples that were apparently standard when checked by the wire manufacturer but were out 6 deg. cent. at some points when checked by the pyrometer maker. This was due in part to the use of different standard curves and in part to errors in cold junction measurements.

For temperature measurements below 320 deg. cent. it is customary to use couples of copper and constantan. They may be relied upon to remain constant to within 0.5 deg. cent. Even up to 500 deg. cent. they will be found accurate and reliable although the copper element oxidizes rapidly at such a high temperature and therefore must be renewed frequently. It is the writer's experience that electrolytic copper taken from various sources and at different times will not vary 0.05 deg. cent. when checked against the same piece of constantan. With the constantan, however, despite its name, one must use caution and not assume that any material supposedly constantan or its equivalent will have the same temperature e. m. f. relation against copper. In fact there is a sufficient variation in a single melt of constantan to demand on the part of the manufacturer that careful checks be made on all coils of wire and even at intervals along a single coil. To show to what extent a single coil of constantan may vary, ten couples were made from the same coil cutting them off in succession from the coil. They were checked with great care so that errors of checking were less than 0.05 deg. cent. The couples differed amongst themselves by 0.1 of 1 per cent at 38 deg. cent., and 0.2 of 1 per cent at 320 deg. cent. Because of the great variation in the e. m. f. of constantan when got from different sources, pyrometer manufacturers have adopted different standards of e. m. f. against copper. For example, the standards of two American makers differ 15.6 deg. cent. at 93 deg. cent. 19 deg. cent. at 200 deg. cent., and proportionately more at higher temperatures. Of course no error results from the use of any couple if the proper e. m. f. temperature relation

considered in greater detail when dealing with particular measurements.

V. Conduction Losses

In measuring temperature with a thermocouple there is, in general, an error introduced due to the fact that the wires of which the couple is composed conduct heat to or from the hot junction. With a good thermal connection between a couple and a good heat conducting solid or liquid no trouble is experienced with couples of small dimensions. Under other conditions, however, large errors may result and are often difficult of elimination or estimate. If, for example, one were to attempt the measurement of the temperature of a cylinder of baked porcelain, even a couple inserted in a hole in the porcelain would be likely to show a large error in its measurement. Heat conducted along the wires of the couple would result in cooling appreciably the temperature of the hot junction. To avoid error from this source it is usual where practical to place fine wire couples with their wires leading away from the point, the temperature of which is to be measured, along a thermally equipotential surface. This eliminates the conduction errors and permits of accurate measurement but of course is a procedure which can be followed only under special circumstances. One might naturally think that a couple of wires so fine as 0.031 in. diameter (No. 22 B. & S. gage) inserted in a fairly deep hole in a porcelain block would closely assume the temperature of the porcelain. But this is by no means true even when the block is of some good conducting material such as metal. A No. 22 gage couple was hammered

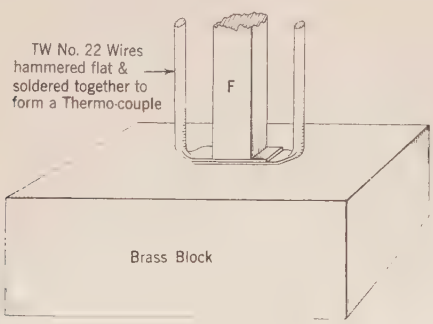

Fig. 2

flat and placed in intimate contact with a brass block at a temperature of 150 deg. cent. See Figure 2. The couple registered 16 deg. cent. low. Pressing the couple firmly against the brass block with a strip of hard fibre, *F*, Figure 2, resulted in reducing the error to 8 deg. cent. This could be reduced still more by using a plastic insulator covering the surface of the couple and the sides but there is always the danger that such a procedure will cause a change in the heat distribution and to that extent give an incorrect measurement. A similar couple with ends well twisted but not flattened and inserted to a depth of ½ in. in a ⅛ in. hole in the block registered 11 deg. cent. low. Figure 3 indicates the arrangement. The couple made contact with the bottom of the hole. Porcelain insulating tubes slipped over the thermocouple wires failed to reduce the error below 8 deg. cent. When the hole was filled with mercury, however, the couple registered correctly to within 0.2 deg. cent. The mere contacting of a couple against a surface whose temperature is to be measured may result in large errors. A No. 22 couple bearing end on against a brass block at 150 deg. cent. registered 67 deg. cent. low. This way of applying a thermocouple is plainly not a practical method but the writer has on several occasions seen couples contacting in

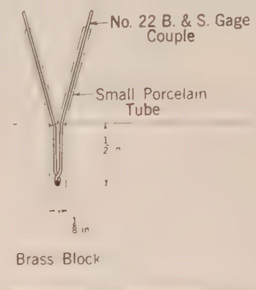

Fig. 3

this manner. It is quite apparent that care must be taken if a surface temperature of a few hundred degrees *C* is to be measured to an accuracy of 10 per cent.

A couple of small dimensions embedded in the material, preferably by peening each couple wire separately into a hole in the body whose temperature is to be measured, is the best approach to ideal conditions and in many cases is a practical means of eliminating conduction errors. Under such conditions conduction errors are negligible. Small couples ranging from 0.013 in. to 0.031 in. diameter when employed in this manner showed errors of less than 0.5 deg. cent. when the extended wires were heated to a dull red and when cooled with ice.

VI. Parasitic E. M. F.

The use of iron constantan thermocouples at high temperatures creates a region of inhomogeneity where the steepest temperature gradient exists. This becomes the seat of local e. m. f. To avoid error from this source in checking or in future use the couples should be immersed to at least an equal depth.

As stated previously, parasitic currents arising from bends and twists are small enough to neglect when using small wires and measuring temperatures of but a few hundred degrees cent.

VII. Lag

In the use of thermocouples it is sometimes required that they be protected from contact with their surroundings by lagging them. This lagging may be for the purpose of protecting them against the chemical action of gases, molten metals or liquids or it may be for the

purpose of electrically insulating them from their surroundings. The errors introduced thereby may be the result of radiation losses or simply due to the thermal resistance introduced. In the latter case the losses due to conduction are accentuated. This subject will be further considered when the various applications are taken up in detail. It might be stated, however, that under some conditions lag may be found of value in steadying the temperature readings from a varying source of heat.

VIII. Cold Junction Temperature

Perhaps the one source of error most often referred to is that arising from the temperature of the cold junction of the thermocouple. It is now well understood that if a thermocouple temperature indicator is calibrated when the cold junction is at one temperature, it will not read correctly when the cold junction is at another temperature unless the instrument is so constructed as to eliminate error from this source. It is not correct, as some makers have assumed, to add to the instrument reading the excess or deficit of cold junction temperature over the calibrated value. The error from this procedure is not large when measuring temperatures of but a few hundred degrees cent. By far the best way, however, is to employ an instrument having a correct automatic cold junction compensator. There is great satisfaction in knowing that when making measurements this source of error is satisfactorily and automatically eliminated by the apparatus itself. This will be particularly appreciated by those who have taken a series of measurements, only later to make the discovery that the cold junction temperature had not been recorded or the position of the hand operated compensator was unknown. When temperatures are to be recorded an automatic cold junction compensator is essential, or otherwise interpretation of the record becomes impossible or burdensome.

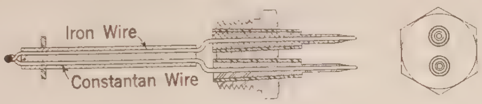

Fig. 4

IX. Measured Temperature Variable

When the measured temperature is varying it is perhaps incorrect to attribute the error to the thermocouple but, as will be shown later, a consideration of the thermal couple design and location will offer a means for lessening any error from this cause. Cases have arisen where lag in the couple has been conducive to better results by offering an average temperature more nearly representative of the mean than would otherwise be secured. Where a recording instrument is employed it may often be so adjusted as to damp out many variations and secure a record more representative and useful through being less subject to constant variation. And where a control mechanism is in use such lagging of the recorder or damping out of its motion may be essential for proper control.

X. Measured Temperature Not Representative

The measured temperature may vary in place rather than time. For example, flue gas temperatures may vary across the section of the boiler passes or down take. Here again the error is not properly an instrument error but one which may be in part, at least, eliminated by giving due consideration to the design of the couple, for example, by using a multiple couple. This will be more fully considered later.

The various applications previously enumerated will now be considered and the methods of dealing with the problems arising will be detailed.

Classification of Temperature Measurement

I. Feed Water

The determination of feed water temperatures is usually made with a mercurial or other type of expansion thermometer. The mercury thermometer placed in a mercury or oil well is in general a sufficiently accurate method of measurement but it often entails placing the thermometer in a more or less inaccessible place and does not permit of recording such temperatures. If a record is desired or if a distant indication is deemed necessary the thermocouple will be found convenient. For this and similar applications a thermocouple has been developed which is capable of withstanding the boiler pressure and convenient to install. When supplied with an automatic cold junction compensator it leaves nothing to be desired in the way of reliability and accuracy, convenience of installation, and ability to have indications or records or both at distant points. This type of thermocouple is in design quite similar to a gas engine spark plug. As indicated in Figure 4, it is so constructed with tapered and insulated leads that the internal pressure acts to prevent rather than produce leaks. For this service no particular care need be taken to avoid errors as when once properly calibrated they should hold their calibration indefinitely. The intimacy of contact with the water whose temperature is measured insures against errors. The relativly low temperatures are within the range of copper constantan couples. There may be cases where stray e. m. f. will demand unusual care in insulating the circuit and instrument but this is a precaution which should be taken in practically any installation.

II. Boiler Water

This problem is similar to that of determining feed water temperatures but in this case we have to contend with both high temperatures and high pressure. The same type of thermocouple plug has been found effective. The plug insulation is of mica and as stated before, the design is such as to preclude the liklihood of

leaks starting due to the pressure and temperature to which the plugs are subjected. In fact, due to improper workmanship some plugs of this type when they were first being experimentally produced did leak when first installed. The temperature and pressure to which they were subjected soon closed up the leak. It has been found practical and safe to tap such plugs directly into a boiler. There has been some discussion as to the temperature distribution throughout the tubes and drums of water tube boilers. Plugs of this type may be tapped into drums and headers and extended into tubes a distance sufficient to enable a study to be made of the relative steaming efficiency of various sections of a boiler. As in the determination of feed water temperatures no serious errors are encountered in this application.

III. Economizer

The determination of the temperature of the gases entering and leaving economizers has been made by means of thermocouples arranged in series and so disposed as to secure an approximation to the average temperature of the gas. In this case the various cold junctions are brought out to a convenient point where a compensator is applied.

When such couples are placed both before and after the economizer a double curve drawing recorder may be employed indicating at each instant the temperature of the entering gas, the temperature of the exit gas and the drop in temperature through the economizer.

IV. Flue Gas

A continuous record of flue gas temperatures may be required or it may be desired to control some other element of operation automatically in terms of flue gas temperature. The thermocouple controller recorder offers a means of accomplishing either or both results.

Kreisinger in Bulletin No. 145 of the Bureau of Mines calls attention to the fact that the major error in the determination of flue gas temperatures is that due to the radiation from the couple to its cooler surroundings unless precautions are taken to prevent such error. He states that under some conditions the error may amount to several hundred degrees in some passes of the boiler. Even in the down take an error of 25 deg. cent. may result from this cause.

In the last pass of the boiler or in the down take the error is always in a direction indicating temperatures lower than actual, owing to the fact that the tubes in the last pass are at a much lower temperature than the gases. For this reason the couple radiates to the tubes and is therefore lowered in temperature. Kreisinger pertinently calls attention to two points: first, that the degree of accuracy of gas temperature measurements depends more upon the judgment of the user of the instrument than upon its correct calibration and second, because an instrument is correctly calibrated, the readings are too often assumed to accurately indicate the temperature of the gas.

The important point to note in gas temperature measurements is that the larger the diameter of the couple or its protecting tube the greater the radiation error will be. While it is usually assumed that a heavy couple or a heavy protecting tube markedly lowers the couple temperature by reason of conduction along the wires or protecting tube such is not generally the case. The conduction error can be made small. The real source of error lies in the fact that a large diameter couple offers a large surface for gain or loss of heat by radiation. With a couple projecting into the hot gases a distance of eighteen inches, conduction error may be ignored. Hence a properly constructed couple for gas measurements should be placed in a substantial steel tube for mechanical strength but the hot junction of the couple should be exposed for a distance of perhaps

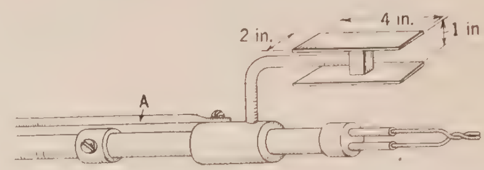

Fig. 5

six inches. The couple wires should be unprotected for this distance and should be not larger than No. 22 B & S. gage. With the low temperature of flue gases 200 to 250 deg. cent. and with a couple constructed as above outlined the gas temperature should be measurable to an accuracy of 3 to 5 deg. cent.

In the last pass of a boiler where the temperature of the gas may be 650 deg. cent. to 750 deg. cent. this type of couple should give a reading not more than 25 deg. cent. low. Experience seems to indicate that for the latter measurement a correction approximating 3 per cent will leave only a small outstanding error and for temperatures in the down take a correction of about 1 per cent will allow for the lowering of temperature due to radiation.

In some tests made for the writer for the purpose of determining the error in flue gas measurements due to radiation, screens or baffles were so located and constructed as to shield the couple from radiation to the boiler tubes. The arrangement is illustrated in Fig. 5. The rod *A* could quickly slide the baffles away from the couple. They could be quickly withdrawn and replaced without disturbing any part of the couple and without loss of time. When readings were made in rapid succession both with and without the baffles, differences of temperature of not over 1 deg. cent. resulted. In this case the couples were of No. 22 gage wire. While this method is a satisfactory means of measuring gas temperature at a point in the flue it does not insure that the measured temperature is a representative one. For this reason multiple couples have been used to secure an average in the same manner as in averaging the temperature of economizer gases.

V. Superheated Steam

The thermocouple because of its rapid response to changes in temperature, has found an unexpected application in connection with the measurement of temperature of superheated steam. If water is carried along with the steam and strikes the thermocouple it lowers its temperature suddenly. A continuous record of the thermocouple temperature, therefore, shows sudden breaks, the cause of which is readily recognized. The application to this service was primarily for the purpose of determining the degree of superheat in making acceptance tests of superheaters. It proved very useful in this respect in that it was immediately responsive to any changes due to change in load and was free from suspicion of error due to lead conduction.

For this service the plug type couple will be found useful. Experience, however, shows that its construction must be carefully attended to in order that it may have sufficient rigidity to withstand the rather high pressure due to the velocity of the steam and the impact of the water.

VI. Bearings

Thermocouples embedded in bearings operate under conditions that insure reliable measurements providing care is taken to secure proper electrical insulation in order that stray currents may not produce errors.

The couple should be set in a hole of such depth that the hot junction is near the running surface and should be made of small wires, otherwise conduction along the wires may result in indicating too low a temperature. Couples constructed and installed as indicated in Fig. 6. have been suggested although the writer cannot say whether they have been tried out.

Fig. 6

This construction grounds the thermocouple since the copper sheath is one element of the couple. Perhaps a better construction would be to use silver for a sheath for only about one inch of length the balance being made of porcelain or light wall german silver. In this case the couple can be made of fine wire and insulated from the sheath.

It is practical to keep not only a continuous record of bearing temperatures but to have the recorder furnish a light or bell signal if the temperature rises above a safe limit.

VII. Generator Windings

After a careful analysis of the design of a machine has indicated the probable hottest region, there remains the problem of so locating the couple as to enable the temperature of the *copper* at this point to be determined.

In service, the couple has to be placed outside the insulation and therefore a correction is necessary for the temperature drop through the insulation. Standard corrections for this drop have been adopted in the Standardization rules of the A. I. E. E.

In a shop test constantan wires can be substituted for some of the small strands in the armature conductors and these constantan leads welded to the armature copper at the hot spots. A potentiometer connected between the constantan lead at the neutral point, if grounded, and the neutral copper will permit determination of the copper temperature. If at the same time additional copper constantan couples are placed outside the copper insulation adjacent to the first couples, simultaneous measurements will give the correction for the latter couples when used in service.

After the test the leads of the inside couple can be cut off.

Thermocouples installed in generators are subject to strong a-c. fields hence they should be so designed as to prevent heating due to eddy currents.

Thermocouples used in generators are always grounded as a protection to the operator but of course only one ground is permissible since the difference in potential between two grounded points may be large in comparison with e. m. f. generated in the couple. Couples should not have common return leads as this gives rise to trouble and also makes it more difficult to locate trouble. Furthermore, trouble in any one couple effects the whole system and not simply its own circuit.

It is almost unnecessary to point out that the leads should be individually insulated with good rubber. The fact that the e. m. f. of a thermocouple is but a few millivolts may lead to the inference that a low insulation is sufficient.

VIII. Transformer Windings

Thermocouples have not been used to any great extent in this country for measuring the temperature of transformer windings. The resistance thermometer has the advantage that it may be placed in an a-c bridge and insulated by means of a special insulating transformer. This is the arrangement used by the General Electric Co.

Large transformers are usually of higher voltage than generators and consequently the insulation problem is more difficult. Even if the "hot spot" could be reached, it would not be safe from the standpoint of life hazard to use undergrounded thermocouples, and it would cause dangerous stresses in the insulation to run grounded thermocouples into the windings in the ordinary manner.

The Westinghouse Company employs an "artificial

hot spot" located in the oil of the transformer and supplied with current from an auxiliary transformer. In this "artificial hot spot" it is safe to place a thermocouple or any convenient type of temperature detector.

Very many high-voltage transformers have one winding connected in Y with the neutral solidly grounded. Accordingly it is possible to place thermocouple leads in the main winding with the instrument connected at the neutral point. This method is now being investigated by one of the transformer manufacturers.

IX. Cables

In the last year or two the thermocouple has been used extensively for temperature measurement in cable systems. The thermocouple is valuable in this work because of its extreme simplicity and robustness.

Where it is possible to solder the couples to the lead sheath of a cable before drawing in, the problem is rather simple. The errors to be avoided are those due to stray e. m. fs. leaking on to the leads, and due to e. m. fs. produced by electrolytic action on the thermocouple leads. The ducts are usually very wet and excellent insulation is required to avoid the errors mentioned.

Most of the measurements have to be made in empty ducts as it is not possible to pull a couple for any great distance into a duct occupied by a cable. However, thermocouples can be pulled into occupied ducts up to limited distances, but there is considerable uncertainty in the measurements as it is quite impossible to tell whether the couple is in contact with the sheath, the duct wall or neither.

Whether the couples are pulled into empty or occupied ducts it is necessary to guard against conduction along the leads and it has been found advantageous to place a small mass at the hot junction in order to reduce conduction errors. This makes it necessary to leave the couple at each point to be measured for a considerable length of time (15 minutes to ½ hour) to allow the mass to assume the local temperature.

Of course the results are affected by radiation from and to the duct walls, but this error is probably small and usually in the direction to show a temperature more nearly that of the cables in adjacent ducts.

Long leads are used with thermocouples for cable measurements and these leads are subjected to varying temperatures along their length. The temperature of leads may be above or below the junction temperature but is not very different. It is necessary to select the lead wire in order to avoid errors due to parasitic e. m. fs. but it has not been difficult to obtain lead wire which is apparently very satisfactory.

The writer is indebted to Mr. I. M. Stein of the Leeds & Northrup Company for the substance of the remarks pertaining to generators, transformers and cables.

ILLUMINATION ITEMS

By the Lighting and Illumination Committee.

EXTRACTS FROM THE REPORT OF THE STREET LIGHTING COMMITTEE OF THE A. S. M. I.

The Report of the Street Lighting Committee of the American Society for Municipal Improvements is of unusual interest in view of the fact this society is composed of mayors, city councilmen, city engineers and others interested in civic affairs whose opinions on street lighting matters are a considerable factor in shaping the trend of street lighting practise.

Among the important points discussed in the 1922 Report of the Street Lighting Committee, consisting of Messrs. C. W. Koiner, Chairman, Earl A. Anderson, and Ralph Toensfeldt, are the following:

A new lamp has been placed on the market which is the most powerful light source which has ever been made available for the lighting of streets. It is a 2500 candle-power (25,000 lumen) gas-filled lamp of the 20-ampere series type. The highest powered light source previously available in the series-type gas-filled lamp was one of 1500 candle-power (15,000 lumen).

There is a very noticeable trend toward the use of larger lamp sizes. It is agreed among engineers that 100 candle-power is the minimum lamp size which it is economical to use for street lighting. Lamps of less than 100 candle-power not only operate at a lower efficiency, but are uneconomical because too great a proportion of the annual street lighting cost of the city (sometimes as much as three-fourths of the total expenditure) is made up of fixed charges on the installation, and only a relatively small part of the expenditure goes for the production of light.

Ornamental lighting equipment is rapidly becoming the standard, not only for business districts and parks but also for thoroughfares and residential streets. It is noted that a very large number of new real estate subdivisions are being lighted by ornamental standards properly spaced before the lots are placed on sale, which is a very desirable practise, for not only are property values increased, but the installation of the underground circuits, erection of posts, etc., can usually be handled much more economically before the streets have been paved, than afterwards.

Among the more notable installations mentioned in the report, which have been made in various cities during the past year, are the East Cleveland street and thoroughfare lighting system; the installation of 10,000 or more units in relighting the entire city of Kansas City, Missouri; the installation of a new system consisting of about 400 units on Summitt Avenue, a beautiful residential boulevard in St. Paul, Minn., the installation of 447 ornamental standards in Mandan, North Dakota, a city of only 4336 people.

Mention is made in the report that there has been a growing interest in the subject of lighting of highways between cities during the past year, stimulated by a desire to increase the safety of night driving on these

thoroughfares. One result of the development of artificial lighting of highways, the report predicts, will undoubtedly be a further increase in night traffic passing through cities and villages, which in turn will require an increased provision for proper illumination of the thoroughfares leading to the municipalities.

A resumé of the survey on the relation of better lighting and accident and crime prevention is contained in the report. According to this survey nearly 600 fatalities are annually chargeable to the lack of illumination; in property value, approximately $54,000,000 of the annual street accident loss is chargeable to the same cause. At the same time it was reported that the total expenditure for street lighting in the United States was not in excess of $50,000,000. The effect of adequate street lighting on crime is cited in the report by showing that the analysis of crimes occurring in the downtown district of Cleveland indicated that the installation of the white-way lighting system could be credited with a decrease of 41 per cent in the amount of crime on those particular streets as compared with the remainder of the city.

The report notes the wide diversity in practise as to the illumination of streets of the same character and importance in different municipalities. These variations have been due in part to differences in local opinion as to the requirements to be fulfilled, but in many cases the extent of available funds has been the important governing factor. With more evidence as to the real value of street lighting, not only from the standpoint of comfort, convenience, and commercial advantage, but also from the standpoint of accident and crime prevention, there appears to be a more definite crystallization of opinion as to the desirable practise for the different classes of streets. Table I has been assembled to indicate the desirable range of practise under present conditions.

In discussing the cost of street lighting, the report states that the cost of street lighting per lamp post has not shown the same ratio of increase as other municipal safety services, such as fire and police protection. It is pointed out that the low average annual expenditure of less than $1.00 per capita for street lighting results from the fact that a great many cities whose lighting was considered satisfactory 10 or 15 years ago have not revised their street lighting systems to make them adequate under the new and more severe requirements brought on by the enormous increase in automobile transportation.

A number of municipalities that have improved their lighting systems throughout the city so that they measure up to modern standards found that the improvement was effectively accomplished at the modest cost of from $1.50 to $2.50 annually per capita, the latter figure in most cases making possible the installation of ornamental standards. The highest expenditure of any city according to a recent comprehensive survey was $4.81 per capita per year. The report calls attention to the fact that comparisons of cost on a per capita basis are sometimes misleading, since there are such great variations in miles of paved street per thousand of population. Various classes of streets will vary the basis of computation depending upon width of streets, arrangements of intersections, amount of foliage, character of paving, and local costs. The report gives the following range of cost of carefully designed ornamental street lighting for different classes of streets, assuming that there are no extreme conditions affecting the cost:

	Annual Cost Per Foot Length of Street	
Business District White Way	$1.00	$4.00
Thoroughfares and Boulevards	0.30	1.20
Residential Streets	0.20	0.80

TABLE I—STREET LIGHTING PRACTISE

Population of City	Street Class	Lamp C. P. Per Post	Mounting Height	Desirable Lamp Spacing Feet	Arrangement of Lamps	Lamps C.P. Per Ft. Length of Street
100,000 or Larger	Principal Business	1000-5000	14-25	80-150	Parallel	20-100
	Secondary Business	1000-2500	14-18	80-125	Parallel	10-50
	Principal Thoroughfares	600-1500	20-25	125-250	Parallel	3-10
	Secondary Thoroughfares, Wholesale & Mfg. District	400-1000	20-25	125-250	Staggered	2-5
	Boulevards and Parks	250-1000	14-20	125-250	Parallel or One Side	1-5
	Residential	250-600	14-20	125-250	Staggered	1-4
	Alleys, Business Section	250-600	16-20	125-250	One Side	2-5
	Outlying Streets and Alleys	100-250	16-20	200-400	One Side	¼-1
20,000 to 100,000	Business	100-2500	14-18	80-125	Parallel	10-50
	Thoroughfares	400-1000	20-25	125-250	Staggered	2-5
	Boulevards and Parks	250-1000	14-20	125-250	Parallel or One Side	1-5
	Residential	250-600	14-20	125-250	Staggered	1-3
	Outlying Streets and Alleys	100-250	15-20	200-400	One Side	¼-1
5,000 to 20,000	Business	600-1500	14-18	80-125	Parallel	5-30
	Thoroughfares	400-1000	20-25	125-250	Staggered or One Side	2-5
	Boulevards and Parks	250-600	14-20	125-250	Parallel or One Side	1-3
	Residential	250-400	14-20	125-250	Staggered or One Side	1-3
	Outlying Streets and Alleys	100-250	16-20	200-400	One Side	¼-1
5,000 or Smaller	Business	250-600	12-16	80-125	Parallel or Staggered	2-10
	Thoroughfares	250-600	16-20	125-250	Staggered or One Side	1-2
	Alleys	100	16-20	200-400	One Side	¼-½
	Highways	250-400	25-35	300-600	One Side	½-1

The Committee recognizes that the 100 c. p. lamps have a place in residential sections, on narrow streets, curbed parkways, in parks, in alleys and certain outlying streets.

CHARACTER OF CONSTRUCTION

Varying types of ornamental equipment are suited for the different classes of streets. For business streets the upright column with a single lamp is most common, though ornamental trolley pole brackets are often used. For intensive or White-Way lighting with 3000 to 5000 candle-power per standard, two-light or three-light units have been adopted. For thoroughfares, boulevards, parks, and residential streets, both ornamental bracket standards and upright standards

are common. In some instances ornamental brackets are attached to trolley poles or other poles already in place. The preference is for underground wiring, though some ornamental poles can be successfully adapted to use overhead wiring. For outlying districts, alleys, and highways, underground wiring is seldom practical.

LIGHTING OF THE FOOD INDUSTRIES*

Although our food industries are highly developed from the standpoint of modern manufacturing methods and sanitary standards, artificial illumination, generally speaking, is an element which has suffered serious neglect. The benefits of good lighting and their relative order of importance in the food industry are, briefly, improved sanitation, increased safety, greater production, reduced spoilage, improved morale and easier supervision of the workers.

Grain Elevators

A survey of lighting practise in one hundred typical grain elevators, ranging from 60,000 to 450,000 bushels capacity, resulted in the following statistics:

Types of Lamps

Plants using all carbon lamps	21
" " all tungsten lamps (vacuum)	42
" " all tungsten lamps (gas-filled)	1
" " carbon and tungsten vacuum	26
" " carbon and tungsten gas-filled	5
" " carbon vacuum and gas-filled	4
" " oil lanterns	1

Use of Reflectors

Plants using no reflectors	85
" " some reflectors	11
" entirely equipped with reflectors	4

Vapor Proof Globe Protection

Plants using no vapor proof globes	41
" partially equipped	46
" entirely equipped	13

Types of Reflectors

Plants using all drop cords	53
" " all ceiling sockets	2
" " ceiling sockets and drop cords	9
" " ceiling sockets and wall brackets	5
" " drop cords and wall brackets	18
" " drop cords, ceiling sockets and wall brackets	13

Types of Wiring

Plants using all conduit wiring	51
" " all open wiring	32
" " open and conduit	17

Lamps

Average number of lamps per plant	230
Average size of lamp used (watt)	40–50

Because of the exceptionally dusty atmosphere existing in grain elevators all lamps should be enclosed in vapor or dust proof globes. This minimizes the fire hazard incident to the accumulation of dust on the lamps or the breakage of a lamp in a dusty atmosphere. An extremely objectionable practise in present day houses is the use of lamps on drop cords for the interior illumination of grain storage bins, as the attendant fire hazard here through lamp breakage, short circuits in the drop cord, etc. is comparatively great. The ideal method of lighting these bins is by means of a portable unit of the projection type which can be mounted at the top of the bin and projected therein. The following tabulation indicates the recommended lighting intensities for grain elevators.

Section	Type of Illumination	Intensity ft. candles
Garner floor	General	1-3
Machinery floor	General	3-4
Garner floor	General	1-3
Weighing floor	General and local	1-3, 8-10
Bin floor	General and local projectors	1-3, ½-1
Cleaning	General	1-3
Conveyor Passageway	General	1-3
Deck and dock	General (flood lighting)	1-3
Cars and ship holds	General	3-4

Flour Mills

Artificial light application in the majority of mills is very poor, the customary procedure being to place low wattage Mazda B lamps on drop cords at the place where light is desired without regard to the procurement of efficient utilization uniform distribution or prevention of glare. General lighting is most admirably adapted to the flour mill and can be best secured by the use of suitably spaced gas-filled lamps in steel dome reflectors preferably equipped with vapor proof globes. In modern flour mill laboratories where flour is inspected and tested with regard to grade and bread making qualities, daylight or artificial illumination of a character enabling accurate color discrimination is essential. The following intensities are recommended as a guide for good lighting levels in this industry.

Process or Operation	Type of Illumination	Intensity ft-candles
Cleaning, grinding, rolling, separating	General	3-6
Bagging and weighing	Localized general	6-8
Grading	Local	10-20

Breakfast Foods

The present lighting practise in this field varies widely with a distinct trend toward high grade general illumination. The following tabulation indicates the recommended lighting intensities.

Process or Operation	Type of Illumination	Intensity ft-candles
Cleaning, grinding, rolling	General	3-6
Baking and roasting	General	5-10

Bakeries

Survey indicates that the majority of baking establishments are using lighting systems which are far

*Abstract of paper presented by W. H. Rademacher at the annual convention of the Illuminating Engineering Society, Swampscott, Mass., Sept. 25-28, 1922.

below a satisfactory and economic standard. In fully 50 per cent of the plants inspected reflectors were found to be a practically unknown quantity. Vacuum lamps ranging from 25 to 60 watts were the prevailing light sources. General illumination answers most of the needs in establishments of this kind except at points where close work such as raisin-picking and fruit-sorting is carried on in which instances localized general lighting is found most satisfactory. In the lighting of the interior of bake ovens a special problem is presented. Because of the high baking temperatures which range from 500 to 750 deg. fahr. short-life lamps result from units mounted permanently within the oven. Several oven manufacturers build lighting equipment as an integral part of their oven and lamp application in such cases is usually such that the lamp is exposed to the baking temperature only during the brief time of inspection. The following tabulation indicates the recommended lighting levels in this industry.

Process or Operation	Types of Illumination	Intensity ft-candles
Blending	General	4-6
Mixing	General	4-6
Dividing and forming	General	4-6
Fruit sorting and peeling	Localized general	10-15
Raisin picking	Localized general	15-18
Baking	General	4-8
Icing	General	4-8
Wrapping	General	4-6

Canning

There is a great variation in the present day lighting practise in this industry. In some plants general lighting employing from ¾ to 1 watt per square foot is being used with localized general lighting at preparation tables and can inspection benches. In small factories, particularly those which function but a few months a year the lighting application is very poor and consists for the most part of the indiscriminate use of bare lamps. In recommending desirable lighting practise for this phase of the food industry too much stress cannot be laid upon the importance of uniform distribution and adequate intensity, particularly in the cutting, peeling and various preparatory operations. Provision must be made so that shadows will not be cast upon the workers as they sit and cut or sort. Grading is one of the most important operations encountered in the cann ng industry. In the case of some products there are as many as five or six distinct grades. In order to discriminate these from the bulk as received, exceptionally good lighting of a character enabling accurate color discrimination is obviously necessary. Daylight Mazda lamps answer this need. Accurate color matching units are also invaluable in the laboratories where color comparisons and tests are made. The following tabulation indicates the recommended levels for the lighting of canneries.

Process or Operation	Type of Illumination	Intensity ft-candles
Grading	Localized general (daylight Lamps)	10-15
Peeling, pitting, husking, cutting, etc.	Localized general	8-12
Washing	General	4-8
Blanching	General	4-8
Can filling, exhausting and closing	General	4-8
Can inspection	Localized general	10-15
Processing and cooling	General	4-8
Labeling and packing	General	4-6

Meat Packing

The Bureau of Animal Industry, of the U. S. Department of Agriculture, Regulation 8 requires that abundant light both natural and artificial must be furnished in all places except coolers, curing cellars, etc. It is advocated that natural lighting be had here if possible. Although Government regulations have done much toward improving sanitary and daylight conditions, in meat packing plants, artificial lighting in many instances is still far from a satisfactory standard. Equipment in common usage is of a wide and in many cases antiquated variety. Local lighting employing groups of small bare lamps is frequently used at the cutting tables, etc., these being the very places where comfortable and adequate light is most essential. The following tabulation indicates the recommended levels for the lighting of packing houses.

Process or Operation	Type of Illumination	Intensity ft-candles
Slaughtering	General	3-6
Hide stripping and dressing	General	8-12
Washing	General	8-10
Inspection	Localized general	12-14
Cooling	General	4-8
Cutting	Localized general	8-10
Cooking, grinding, sausage stuffing, etc.	General	6-8
Curing		2-4

Ice Cream Manufacturing

The lighting practise in this industry is the poorest found in any of the so called food industries. General lighting of a moderate intensity answers all demands. The following tabulation indicates the recommended levels for the lighting of such plants.

Process or Operation	Type of Illumination	Intensity ft-candles
Mixing	General	4-6
Freezing	General	4-6
Coolers	General	3-4

Chocolate and Candy Manufacturing

Many of the large plants inspected in this phase of the food industry were found to be using admirably applied general illumination with intensities ranging from 4 to 6 foot-candles. Others were found to be using haphazard applications of bare lamps on drop cords and

these apparently are still in the majority. There are no difficult problems involved in the lighting of these factories and general illumination properly applied is usually found well suited to all areas.

The following tabulation indicates the recommended levels for the lighting of such plants:

Process or Operation	Type of Illumination	Intensity ft-candles
Chocolate		
Cleaning and sorting.....	General	4-8
Husking, sieving and winnowing..............	General	4-8
Milling................	General	4-8
Fat extraction..........	General	4-8
Crushing, sifting, mixing and refining........	General	4-8
Kneading and moulding.	General	4-8
Setting................	General	4-8
Wrapping..............	General	5-10
Candy		
Mixing................	General	4-8
Cooking...............	General	4-8
Moulding and dipping...	General	5-10
Wrapping..............	General	5-10

Fruit Packing

By far the most important operation in fruit packing is that of grading. Classification is usually carried on with careful reference to size, shape, color, degree of ripeness, blemishes, bruises, etc. Extremely good lighting enabling fairly accurate color discrimination is highly essential in this work. The daylight Mazda lamp is admirably adapted to the illumination of such operations. All other lighting demands can be well taken care of by the use of regular Mazda lamps. The following tabulation indicates the recommended lighting levels for fruit packing establishments:

Process or Operation	Type of Illumination	Intensity ft-candles
Cleaning.............	Localized general .	3-6
Grading..............	Local	8-12 daylight lamps
Wrapping............	Localized general	3-6

Milk Treating

General lighting supplemented by local or localized general lighting at inspection points is usually employed in milk treating plants and is well adapted to the work carried on. The following tabulation indicates the recommended lighting levels for such establishments:

Process or Operation	Type of Illumination	Intensity ft-candles
Pasteurizing, bottling and capping................	General	4-8
Bottle inspection..........	Local or localized general............	10-12
Cooling..................	General	2-4
Can and bottle washing....	General	2-4
Shipping.................	General	1-2
Condensing...............	General	4-8
Evaporating..............	General	4-8

DIELECTRIC LOSSES IN CONDENSERS

A comparative study of the methods which are used in measuring dielectric loss in condensers, especially those having a large value of capacitance is being made by the Bureau of Standards, which has an air condenser with a capacitance of 1/10 of a microfarad which will withstand 3000 volts without any appearance of corona. The losses in other condensers may be compared with this air condenser which has negligible loss by means of bridge methods. This is not only the most accurate and dependable method of measuring dielectric loss but also is one of the simplest when there is available a condenser having known losses.

On account of the difficulty of maintaining a condenser of known loss, many of the manufacturing concerns have used other methods for measuring dielectric loss, the principal ones being the electro-dynamometer method and the electro-static wattmeter method. Although these methods determine the loss in terms of well-established units, the correction terms in the formulas which must be applied are of such importance in measuring condensers with low power loss that there is often considerable uncertainty in the results. It is the purpose of the Bureau to study these methods carefully and to learn the importance of the various factors which enter into the determination.

EXTENSION OF POWER LINES IN MEXICO

A contract has recently been entered into by the government of the State of Chihuahua, Mexico, and the Compania Agricola y de Fuerza Electrica del Rio Conchos, S. A., whereby this company is granted a concession to extend the power lines from its present hydroelectric plant at Boquilla to Chihuahua and the near-by smelter and mining camps.

The contract extends the original concession granted to this company until the year 1941; provides for an increasing scale of taxation; sets the maximum rates to be charged for various classes of electric power; and establishes a limit of nine months for the construction of lines to Ciudad Camargo and 15 months for those to Chihuahua.

The high-tension lines to be constructed will be each approximately 90 miles long and the entire work, including towers, relay stations, transformers, etc., will cost, it is reported, approximately $700,000.

The Boquilla hydroelectric plant, which is reported to be potentially the second largest in the world, is Canadian owned. The dam across the Conchos River from which power is secured was built about 1906, but at the outbreak of the revolution in Mexico in 1910 the power lines had been extended only to Parral, so that at the present time only a very small fraction of the available power is being utilized.

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The Institute is not responsible for the statements and opinions given in the papers and discussions published herein. These are the views of individuals to whom they are credited and are not binding on the membership as a whole.

The Eleventh Midwinter Convention

NEW YORK, FEBRUARY 14-17

As previously announced, the Eleventh Midwinter Convention of the A. I. E. E. will be held in New York, February 14-17, in the Engineering Societies Building, 33 West 39th St. The tentative program given in the January JOURNAL and in preliminary announcements has been confirmed practically without change by the Meetings and Papers Committee and includes six technical sessions with 32 papers, one session being a joint meeting with the Chicago Section by means of long-distance telephone and loud speakers.

Other features of special interest are an illustrated lecture on electric railway practise by Mr. William B. Potter, a "get acquainted" smoker given by the New York Section, at which the pallophotophone will be demonstrated, the usual dinner-dance which has become a feature of our midwinter conventions, and a number of inspection trips during and after the convention.

The program follows:

PROGRAM

WEDNESDAY MORNING, FEBRUARY 14

Committee meetings to be announced.

Foyer—11 A. M.

Registration of members and guests begins.

WEDNESDAY AFTERNOON

2:30 P. M.

TECHNICAL SESSION

Report of Transmission and Distribution Committee, E. B. Meyer, Chairman, Asst. Chief Engineer, Public Service Electric Co., Newark, N. J.

Apparent Dielectric Strength of Cables, by R. J. Wiseman, Okonite Co., Passaic, N. J.

Short-Circuit Currents in Networks, by O. R. Schurig, General Engineering Laboratory, General Electric Company, Schenectady, N. Y.

Qualitative Analysis of Transmission Lines, by H. Goodwin, Jr., Sanderson & Porter, New York, N. Y.

The Heavisidion, by Vladimir Karapetoff, Professor of Electrical Engineering, Cornell University, Ithaca, N. Y.

Cable Testing and Maintenance, by H. S. Phelps, Engineering Dept., and E. D. Tanzer, Transmission Dept., Philadelphia Electric Co., Philadelphia, Pa.

WEDNESDAY EVENING

8:30 P. M.

NEW YORK-CHICAGO JOINT SESSION

Public Address Systems, by I. W. Green, of the American Telephone and Telegraph Co., and J. P. Maxfield of the Western Electric Co., New York, N. Y.

Use of Public Address Systems with Telephone Lines, by W. H. Martin, Dept. of Development and Research, American Telephone and Telegraph Co., New York, N. Y.

LECTURE

Observations on Electric Railway Practise, by William B. Potter, Chief Engineer, Railway and Traction Department, General Electric Company, Schenectady, N. Y.

THURSDAY MORNING, FEBRUARY 15

10:30 A. M.

TECHNICAL SESSION

Automatic Train Control Problems, by E. J. Blake, Electrical Engineer, Gould Coupler Co., Depew, N. Y.

Application and Economics of Automatic Railway Substations, by L. D. Bale, Engineer of Substations, Cleveland Railway Co., Cleveland, O.

Single-Phase Regeneration for Series Commutator Motors, by L. J. Hibbard, Railway Equipment Engineer, Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.

The Blondelion, by Vladimir Karapetoff, Professor of Electrical Engineering, Cornell University, Ithaca, N. Y.

Transient Conditions in Electrical Machinery, by W. V. Lyon, Asst. Professor of Electrical Engineering, Mass. Inst. of Tech., Cambridge, Mass.

1922 Developments in Autovalve Lightning Arresters, by A. L. Atherton, Supply Engineering Dept., Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.

THURSDAY AFTERNOON

2:30 P. M.

TECHNICAL SESSION

Telephone Transmission Over Long Cables, by A. B. Clark, Engineering Dept., American Telephone & Telegraph Co., New York, N. Y.

Machine Switching, by E. B. Craft, Chief Engineer, Western Electric Co., Inc., New York, N. Y., L. F. Morehouse, Equipment Engineer, American Telephone & Telegraph Co., New York, N. Y., and H. P. Charlesworth, American Telephone & Telegraph Co., New York, N. Y.

Wind Shielding Between Conductors, by F. J. Howe, Construction Engineer, Western Union Telegraph Co., New York, N. Y.

Wave Antenna, by Harold H. Beverage, Chester W. Rice and Edward W. Kellogg, all of the General Electric Company, Schenectady, N. Y.

Theory of Electric Filter Circuits, by L. J. Peters, Electrical Laboratories, University of Wisconsin, Madison, Wis.

Diaphragmless Microphone, for Radio Broadcasting, by Phillips Thomas, Research Engineer, Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.

THURSDAY EVENING

8:30 P. M

Smoker under the auspices of the New York Section of the A. I. E. E., at which motion pictures will be exhibited, showing new method of speech transmission.

FRIDAY MORNING, FEBRUARY 16

10:30 A .M

TECHNICAL SESSION

Dissymmetrical Electrical Networks, by A. E. Kennelly, Professor of Electrical Engineering, Harvard University and Mass. Inst. of Tech., Cambridge, Mass.

New Equation for Static Characteristics of Electrical Arcs, by W. B. Nottingham, Fellow of American-Scandinavian Foundation, Westfield, N. J.

Radiation from Transmission Lines, by Charles Manneback, Post-Graduate Student, Mass. Inst. of Tech., Cambridge, Mass.

Electromagnetic Forces; A Search for More Rational Fundamentals; A Proposed Revision of the Laws, by Carl Hering, Consulting Engineer, Philadelphia, Pa.

Physical Interpretation of Complex Angles and Their Functions, by A. Boyajian, Technical Engineer, General Electric Co., Pittsfield, Mass.

Permeability, by T. Spooner, Electrical Engineer, Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.

FRIDAY AFTERNOON

2:30 P .M.

TECHNICAL SESSION

Application and Limitation of Thermocouples for Measuring Temperature, by I. B. Smith, Research Dept., Leeds & Northrup Co., Philadelphia, Pa.

Measurement of Power in Polyphase Circuits, by C. Fortescue, Electrical Engineer, Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.

Kilovolt-Ampere Demand Measurement, by H. C. Fryer, Supt. of Meters, Union Gas & Electric Co., Cincinnati, O.

Expansion of Oscillography by Portable Instrument, by J. W. Legg, Consulting Engineer, Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.

Measurement of Transients, by F. Terman, Student at Leland Stanford University, Stanford, Calif.

Balance Methods in A-C. Measurement, by P. A. Borden, Hydro-Electric Power Commission Laboratories, Toronto, Ont.

FRIDAY EVENING

7:00 P. M.

Annual Dinner-Dance.

SATURDAY MORNING

Visists of Inspection.

Dinner-Dance

A Dinner-Dance will be held at the Hotel Astor, Broadway and 44th Street, New York, Friday evening, February 16, 1923, at 7:00 o'clock. The purpose of the Dinner-Dance is to provide a social function for the entertainment of the members and their guests in attendance at the convention.

An informal reception will precede the dinner and prompt attendance is desired in order that the Entertainment Committee's arrangements may be carried out as planned.

The subscription price is $5.00 per person. Reservations accompanied by check should be forwarded promptly as it is absolutely necessary for the Committee to arrange for accommodations well in advance.

The tables will accommodate eight or ten persons each. Members are requested to make up parties of eight or ten or to state their seating preference to the Committee. Communications should be addressed to the Committee on Entertainment, A. I. E. E., 33 West 39th Street, New York.

Inspection Trips

As has been the custom in the past, arrangements will be made for the inspection by members and guests of plants and points of engineering interest about New York. No day could be set aside solely for this purpose because of the number of technical sessions but it is hoped that a variety of trips will be possible during certain hours on each Convention day including Saturday morning. Complete information will be included in the final Program to be distributed at the Registration Bureau at which time directions for reaching plants may also be obtained.

Hotels

Visiting members are advised to make their hotel reservations at the earliest possible date, by communicating directly with the hotel concerned.

Spring, Annual and Pacific Coast Conventions

SPRING CONVENTION IN PITTSBURGH

The Spring Convention Committee in connection with the Meetings and Papers Committee has fixed the dates of the Pittsburgh Convention on April 24-25-26. The headquarters of the Institute during the convention will be the William Penn Hotel, where the technical sessions will be held.

Tentative arrangements have been outlined which assign the morning of Tuesday to registration of members and guests and to committee meetings. The afternoon and evening of this day will be devoted to technical sessions. On Wednesday a technical session will be held under the auspices of the Protective Devices Committee and this session will close promptly at noon, at which time a visit to the East Pittsburgh plant of the Westinghouse Electric & Manufacturing Co. is proposed. There will be no session scheduled for Wednesday evening. On Thursday morning, the last day of the meeting, the technical program will be under the auspices of the Electrochemical and Electrometallurgical Committees, and in the afternoon of that day a radio session is proposed at which papers will be presented on the applications of radio to power transmission. It is also proposed to close the session with a dinner dance on Thursday evening.

The committees appointed by President Jewett to make the necessary local arrangements are as follows:

E. C. Stone, Chairman, J. J. Booth, J. R. Buchanan, P. S. Donnell, W. C. Goodwin, Geo. S. Humphrey, O. Needham, E. G. Peterson, A. G. Pierce, G. W. Quentin, L. H. Rosenberg, M. E. Skinner, H. W. Smith, N. W. Storer.

ANNUAL CONVENTION AT SWAMPSCOTT, MASS

The Annual Convention of the Institute is to be held at the New Ocean House, Swampscott, Mass., June 25-29, 1923. President Jewett has appointed the following General Convention Committee:

A. E. Kennelly, Chairman, F. M. Gunby, Vice-Chairman, W. R. McCann, Secretary, A. W. Berresford, F. P. Cox, E. E. F. Creighton, N. J. Darling, F. L. Hutchinson, C. W. Kellogg, E. L. Moreland, F. J. Rudd.

Various other convention committees have been appointed, the chairmen of which are as follows:

Hotel and Information, F. P. Cox; Finance, C. W. Kellogg; Entertainment, N. J. Darling; Publicity, H. S. Knowlton; Transportation, F. J. Rudd; Attendance, E. L. Moreland; Past-Presidents, Elihu Thomson.

Tentative plans contemplate emphasizing the social functions for which most of the afternoons and evenings will be left open. It has been suggested that parallel sessions be held in case the regular morning sessions do not afford sufficient time for the technical program.

PACIFIC COAST CONVENTION AT DEL MONTE, CAL.

The plans for the Pacific Coast Convention which will be held at Del Monte, Cal., beginning Tuesday, September 25 are

well under way. This meeting will be held under the auspices of the San Francisco Section, and the program will feature recent advances in high-voltage transmission and hydroelectric developments of the West.

The following Committee on Arrangements has been appointed by President Jewett:

Prof. Harris J. Ryan, Chairman, Robert Sibley, Vice-Chairman, Miss C. Grunsky, R. A. Balzari, Henry Bosch, Jr., W. C. Heston, H. W. Hitchcock, W. P. L'Hommedieu, S. J. Lisberger, H. H. Millar, R. F. Monges, W. B. Sawyer, Jr.

Nomination of New York Section Officers for Year 1923-24

The time is very rapidly approaching when consideration must be given to the question of nomination of officers of the New York Section for the administrative year 1923-24. The present officers are particularly anxious to receive suggestions as to candidates for the coming elections and wish to call attention to Sec. 11 of the N. Y. Section By-Laws governing election of officers which provides for the nomination of officers by petition signed by at least ten members of the Section. There are four officers to be elected each year, as follows: Chairman, Secretary-Treasurer, and two members of the Executive Committee. Last year not a single suggestion was received from the membership in spite of the fact that every effort was made to advertise the fact that nominations were open and very welcome to the Committee. It is hoped this will not prove to be the case again this year as the present officers have been very earnest in their desires and attempts to inject new life into Section activities. If you know of a real live wire, get together, make up a petition, your Nomination Committee when appointed will be very thankful for all suggestions. Section 11 of the By-laws follows:

Sec. 11. Officers shall be elected by letter ballot. Not later than February fifteenth of each year the Executive Committee of the Section shall appoint a Nominating Committee of five members of the Section, which committee shall receive and consider any suggestions that may be offered by any member of the Section, and shall place a list of their nominees in the hands of the Secretary not later than March tenth. The Secretary shall prepare and forward to each member of the Section, not later than March twentieth, a ballot containing the nominations made by the committee and, in addition, any other names nominated by petition or by separate endorsement of not less than ten members, received by the Nominating Committee or by the Secretary, in writing, prior to March tenth

Address your communications to A. E. Waller, Secretary N. Y. Section, A. I. E. E., 33 West 39th St., New York, N. Y.

Future Section Meetings

Boston.—February 13, 1923. This will be the annual dinner of the affiliated Technical Societies of Boston. It will be followed by the motion picture address by Mr. A. A. Northrop of Stone & Webster, Inc., Boston. The subject shown will be the "Caribou Hydroelectric Development."

March 13, 1923. Subjects: "Design of Transformers and other Features of the Queenston Plant at Niagara Falls," by Mr. M. E. Skinner, Asst. General Manager, Duquesne Light Co., Pittsfield, Mass., and "The Trend of Power Transformer Development," by Mr. M. O. Troy, Manager, Transformer Dept., General Electric Co., Pittsfield, Mass.

April 16, 1923. Subject: "The Panama Canal, Operation, Traffic and Future," by Brigadier-General Chester Harding, U.S.A.

Detroit-Ann Arbor.—February 9, 1923. Mr. D. H. Baer, Chief Electrician Morgan & Wright Co., will give a general description of the various kinds of electrical equipment required in a large modern tire-making plant.

March 16, 1923. Associate Technical Society Meeting, sponsored by the A. I. E. E.

Lehigh Valley.—February 15, 1923. Subject: "Electric Furnaces" and "Industrial Heating." Speaker: Mr. R. B. Thomas.

Philadelphia.—February 12, 1923. Subject: "Recent Developments in the Electrical Industry with Particular Reference to Practise." Speaker: Mr. L. W. W. Morrow of the *Electrical World*.

March 12, 1923. Subject: "Recent Developments in Thermionic Tubes." Speaker: Mr. Saul Dushman of the General Electric Co.

Pittsfield.—February 15, 1923. Speaker to be announced.

March 1, 1923. Dr. Rowland Rogers, Vice-President and General Manager of the Picture Service Corp. will speak on "Behind the Screen with the Movie Makers."

Toronto.—February 9, 1923. Subject: "Carrier Current." Speaker: Mr. Vennes.

Worcester.—February 15, 1923. Subject: "Interior Wiring." Speaker: Prof. A. L. Cook, Pratt Institute, Brooklyn, N. Y.

March 15, 1923. Ladies' Night. Subject: "The Development of Illumination." Speaker: Mr. W. D'A. Ryan, General Electric Co.

127th Meeting of American Institute of Mining and Metallurgical Engineers

On February 19-22, 1923 the American Institute of Mining and Metallurgical Engineers will hold its 127th meeting at the Engineering Societies Building, 29 West 39th St., New York, N. Y. A list of the various scheduled events follows:

Monday, February 19th

9.00 a. m.—Registration
9.30 a. m.—Ground Movement and Subsidence—7 papers
9.30 a. m.—Petroleum and Gas—Meeting for Organization
12.30 p. m.—Luncheon for members and guests at headquarters
2.00 p. m.—Symposium on Petroleum and Gas—13 papers
2.00 p. m.—Breakage and Heat Treatment of Drill Steel—2 papers
2.00 p. m.—Industrial Relations Session—Reports of Subcommittees
2.00 p. m.—Metallurgy—4 papers
4.00 p. m.—Lecture "Solid Solutions"
8.00 p. m.—Smoker

Tuesday, February 20th

9.30 a. m.—Annual Business Meeting of Institute: On adjournment of Business Meeting, simultaneous sessions will be held on Mining Methods—3 papers, Coal—4 papers, Petroleum—8 papers
12.30 p. m.—Luncheon at headquarters
2.00 p. m.—Institute of Metals Division—6 papers
2.00 p. m.—Joint Session, Iron and Steel and Coal and Coke—5 papers
2.00 p. m.—Symposium on Petroleum and Gas—7 papers
2.00 p. m.—Mining Session—4 papers
8.00 p. m.—Moving Pictures and Dance

Wednesday, February 21st

9.30 a. m.—Iron and Steel Session—3 papers
9.30 a. m.—Local Section Convention
9.30 a. m.—Joint Session Industrial Relations Committee and Mining Section of National Safety Council
12.30 p. m.—Luncheon at headquarters
2.00 p. m.—Institute of Metals Division—6 papers
2.00 p. m.—Iron and Steel Session—4 papers
2.00 p. m.—Joint Session of Industrial Relations Committee and Mining Section of N. S. C.
2.00 p. m.—Joint Meeting with Mining and Metallurgical Society—Technical Education—3 papers
3 to 5 p. m.—Reception at Senator Clark's
6.45 p. m.—Reception and Annual Dinner

Secretary Rice of A. S. M. E. to Describe South American Trip

An invitation is extended by the Metropolitan Section of the A. S. M. E. to A. I. E. E. members to attend a meeting at 8.15 p. m. on February 1, 1923 in the Auditorium, Engineering Societies Building, 33 West 39th St., New York at which Calvin W. Rice, Secretary of the American Society of Mechanical Engineers will tell of his recent trip to South America. This talk will be illustrated with a short motion picture film and numerous lantern slides. Mr. Rice attended the Brazilian International Engineering Congress at Rio de Janeiro in September 1922 as a member of a delegation of engineers representing various engineering societies in this country.

International Conference on High-Tension Transmission in France

The report of the International Conference on High-Tension Transmission, held in Paris, November 21, 1921, has just been completed. Mr. Tribot Laspiere, Secretary General of the Conference took charge of the publication of the report which contains the full record of the proceedings of the conference in a volume of 1200 pages, illustrated by 350 photographs, maps, plans, graphs and drawings. Its contents are roughly divided into four parts: The object of the conference; a general report by Mr. Boucherot; the text in full of the 63 reports presented; and the stenographic reproduction of the discussion following each report.

Subscribers will receive their copies immediately. Those who have not subscribed and wish to do so are informed that there are only 150 copies left and that the book will not be reprinted. They are asked, therefore, to send their orders as soon as possible to the Union des Syndicats de l'Electricite, 25 Bd. Malesherbes, Paris, France.

The American-Scandinavian Foundation Fellowships for 1923-24

In April this Foundation will award to students of American birth twenty Fellowships for study in the Scandinavian countries during the academic year 1923-24. These Fellowships,—ten for study in Sweden, five for study in Denmark, and five for study in Norway,—will bear stipends of at least $1000 each.

It is important that we appoint men and women capable of independent research and study who can worthily represent their colleges and the United States. Scandinavian estimation of American educational institutions will depend upon the successful selection of these Fellows. Graduate students and the younger instructors and professors in American colleges are especially invited to become candidates for our Fellowships. Graduates of the current year are also eligible. For those who are mature enough to carry on independent research, the language will not present great difficulties. Those carrying on undergraduate studies will have to attend lectures in the Scandinavian languages.

We propose the following procedure. All applicants from any one university, college or institute will present before March 1 their applications and supporting papers to the President thereof or to another official designated by him. These papers will then be considered by the Scholarship Committee of the college or some other official committee; and, if possible, the candidates will appear before them. The committee will pass upon the candidates, will rate them in order of merit, and forward their nominations arranged in the order of preference with the supporting papers of each candidate to the Foundation. Our jury will then be able to choose intelligently, having before them the papers of candidates actually approved by the colleges. The number of nominations to be made by each college is left entirely to the discretion of the college. Further details can be obtained by addressing the American-Scandinavian Foundation, 25 W. 45th St., New York City.

American Engineering Standards Committee

REPORT OF WAYS AND MEANS COMMITTEE

The Ways and Means Committee, of which Mr. A. W. Whitney is chairman, proposes to go direct to industry and solicit "Contributing-Memberships" on the basis of approximately 2/1000 of one per cent of gross annual income, or two cents per $1000, according to the following table:

Gross Income in Millions	Contribution of Member
0—1	25
1—2	50
2—3	75
3—5	100
5—7.5	150
7.5—10	200
10—15	300
15—25	500
25—37.5	750
37.5—50	1000
50—75	1500
75—100	2000
100—125	2500
125—150	3000
150—200	4000
200—250	5000
250—300	6000

The gross income thus represented amounts to about 16 billion dollars. We have discounted this down to 5 billion dollars for safety. 2/1000 of one per cent upon this basis will amount to $100,000. This again is twice the minimum we shall be satisfied in raising, so that we have a factor of safety of at least 6. Furthermore, we expect a good many contributions of $25 from concerns that have not been listed because they have an income of less than a million dollars.

Various other plans have been considered, but the only one which seemed feasible was the one based on gross income.

It is recommended that a special service be given contributing members in the form of information bulletins on standardization work in this country and abroad. This proposed service is to be featured in soliciting memberships. Nevertheless, the main emphasis is to be placed on the fundamental service to industry which the A. E. S. C. is rendering through its regular work.

The information service is to be similar to the work which has been started in a very small way, in calling to the attention of cooperating bodies and the technical press, important developments in standardization work, foreign as well as American. To render an adequate service of this kind, one which may properly be featured in soliciting sustaining-memberships, it will be necessary to have an engineer-translator giving practically whole time to the work. This, with necessary clerical support, must be reckoned at about $5000 per year. It will, of course, greatly strengthen the work as a whole, through the help it will be to sectional committees and sponsors.

This plan is being submitted for approval to the members of the Advisory Committee.

The Chairman takes pleasure in acknowledging the kindness

of the United Electric Light and Power Co. in placing at the disposal of the Committee, the services of Mr. R. B. Grove and a staff of clerks who have rendered invaluable service in the development of the plan.

CONFERENCE ON WALKWAY SURFACES SAFETY CODE

A conference to consider the advisability and feasibility of formulating a national safety code on walkway surfaces, has been called by the American Engineering Standards Committee, to be held in Room No. 2, Fifth Floor, Engineering Societies Building, New York City, February 14th, at 9:30 a. m.

Forty trade associations, technical societies, safety organizations, and government departments, have been invited to send representatives to this meeting.

The importance of the subject of this conference is emphasized in a letter from a group of representative manufacturers of safety tread materials, to the American Engineering Standards Committee, which points out that approximately 15,000 persons are killed in the United States each year by falls of various sorts, and that nearly one-half of these falls occur on stairs and floor levels. Fatalities due to falls, in fact, constitute about one-fifth of the total number of accidental deaths from all causes. The Safety Committee of the National Electric Light Association has reported that among 69 companies in 22 different states, accidents due to falls resulted in a greater amount of lost time than those due to any other cause.

AMERICAN ENGINEERING COUNCIL

AN OPPORTUNITY TO RAISE THE PATENT EXAMINER'S SALARIES

The individual members of the Engineering Societies, by giving their powerful aid in securing the enactment on February 18, 1922, of the Lampert Patent Office Bill, H. R. 7077, helped to stop the disintegration of the Patent Office by constant resignations and prevented its complete collapse. Without this help it would soon have been swamped and ceased to function usefully.

The Lampert Bill raised the salaries of the Patent Office Examiners to $3900 per year and stopped the resignations in the upper grades, where it was most important to stop them. However, the increase from $2750 to $3900 was by far the largest proportionate increase that had ever been obtained through any bill in congress and was all that it was possible to obtain at one time. The increased salary is not sufficient, however, to attract men who are highly qualified for the work and to induce them to make a life career of the position, as they must do in order to reach their highest efficiency, in such numbers as to supply all or nearly all of the examining divisions.

The work of an examiner is of great importance to the public interest. By having examiners with sufficient scientific and judicial qualifications and sound judgment and adequate personality, patents will be granted wherever the invention warrants it, and not be refused because the distinctions of the prior art, although important, are not easily discerned. Such examiners will also with sound judgment detect those cases where the distinctions between the alleged invention and the prior art are not really practical commercial distinctions, but are mere paper differences, and will thereby prevent the granting of patents which can only result in useless litigation that is expensive not only to the patentee and his bankers but to the innocent defendant and the government in the waste of time of the courts.

The inventions which examiners must pass upon are often of great immediate value, and their ultimate value, through their permanent addition to the public domain, are beyond calculation. Therefore, the administration of the Patent Office under examiners of the high type mentioned will increase the market value of patents and thereby stimulate the production of inventions in general to the great and permanent benefit of the American public.

It is believed that the salary of $5000 for a primary examiner would attract sufficient men of the type described to fill that position in practically all of the examining divisions. There is an excellent opportunity to obtain that salary for the position by aiding in bringing about the enactment of the Sterling-Lehlbach Bill for the Reclassification of Governmental Positions and Salaries, H. R. 8928. This bill has passed the house by a large majority, but in doing so the salary for the position of primary examiner was reduced from $5040 to $4600. The Civil Service Committee of the Senate has reported the bill recommending a restoration to $5040. As the bill affects appropriations, it was also referred to the Appropriations Committee of the Senate, and has been kept there nearly a year by the desire of Senator Reed Smoot to substitute another bill which, while having a different scheme of classification, has substantially the same schedule of salaries.

As the Sterling-Lehlbach Bill has already passed the House, it would obviously be much easier to enact than substitute a bill. The information is that if sufficient public interest is shown, a compromise not affecting the salaries could probably be brought about and the Sterling-Lehlbach Bill reported to the Senate; and if that is done the bill can be passed through the Senate without great difficulty, after which it seems likely that the House can be induced to agree to the larger salaries.

The Bill has been approved by the following organizations:

The New York Patent Law Association,
The National Federation of Federal Employes,
The American Federation of Labor,
The Federated American Engineering Societies,
The American Association of Engineers,
The National Civil Service Reform League, and others.

The engineers, chemists, scientists and manufacturers proved with the Lampert Bill that they could induce Congress to pass a just and wise measure in the face of intense opposition. There is no such opposition to the present bill as there was to that bill. Each member of each of the Engineering Societies is asked to write to Senator Reed Smoot and to each of his own Senators, urging the immediate enactment of the Sterling-Lehlbach Reclassification of Salaries Bill, H. R. 8928, so far as the schedule of professional salaries recommended by the Senate Civil Service Committee is concerned, and also to write to his member of Congress to the same effect.

If every member will do his duty, it seems more than probable that the bill can be passed and the Patent Office be placed on that high plane which its great usefulness warrants.

The enactment of this bill would raise the standard of all professional service under the Government as well as that of Patent Office examiners.

Let us all pull together and finish the work which we have so successfully begun.

EDWIN J. PRINDLE,
Chairman, Patents Committee,
American Engineering Council.
CHARLES A. TERRY
F. N. WATERMAN,
Representatives of the A. I. E. E. on the Patents Committee, American Engineering Council.

SECOND ANNUAL MEETING IN WASHINGTON

The second Annual Meeting of the American Engineering Council of the Federated American Engineering Societies was held at the Cosmos Club, Washington, January 11-12.

Dean Mortimer E. Cooley of the University of Michigan was unamimously reelected president of the Council for 1923. He struck the keynote of the gathering in saying:

"We are, I feel, entering upon a new era. The engineer, not so much in the technical as in the social sense, is about to take that part in the world which rightfully is his. I am speaking

not of civil engineering, mechanical engineering, chemical engineering, electrical engineering, or any other branch of engineering, but of the engineering profession as a whole."

Dean Cooley, reviewing the year's work said that substantial results had been achieved, and that the Federation was progressing gradually and surely toward the fulfillment of its mission. His trip through eighteen states last spring, he said, inspired the conviction that the Federation was a necessary instrument of organized engineering and a source of opportunity for service both within and without the profession that exceeded the hopes even of its founders. The Waste Report and the Report on the Two-Shift Day in Continuous Industry he characterized as two outstanding accomplishments of world importance. The Two-Shift Report is now available in printed form, and the Committee which prepared it has been formally discharged by the Executive Board of the Council. A third undertaking of similar magnitude was likely to be set in motion in the near future, Dean Cooley announced.

Dean Cooley enumerated many activities in which the Federation might utilize the services of the engineer for the national good. Transportation he mentioned as a field for possible engineering effort through the Federation, whose work in reforestration, delayed by illness in the family of the committee chairman, would soon be constructively resumed.

Appealing for the personal cooperation of every member of the Council, Dean Cooley concluded:

"After fifteen months of service as president of the Federation I am convinced that the opportunities of the engineer are very great. I have the utmost faith that the engineering profession of this country and, through affiliation with foreign organizations, of the world can bring to pass a new epoch in man's history."

The report of Executive Secretary L. W. Wallace, who was reelected by the Executive Board, showed that the activities of the Federation were multiplying rapidly. Relations with government departments are becoming more extensive and more intimate and in every direction the Federation is winning increased recognition. A letter from Secretary Herbert Hoover, read at the meeting, asserted that the Federation was one of the most influential existing agencies in the promotion of public good.

Federal legislation in which the Federation through the executive secretary has taken an active interest includes the Sterling-Lehlbach bill, topographic mapping, helium, national hydraulic laboratory, and revision of the mining laws. John R. Freeman was the principal witness at the hearings on the question of a national hydraulic laboratory, the need for which he pointed out in an exhaustive report. Mr. Wallace asserted that the bill for mining law revision should receive the active attention of all engineers. Adoption of an amendment increasing the appropriation for topographic mapping from $325,000 to $500,000 was called by Mr. Wallace "a distinct victory auguring well for the Temple bill." He reported a tendency to delay action on the Sterling-Lehlbach bill, and this he described as unfortunate.

A resolution introduced by John L. Harrington of Kansas City, Mo., president of the American Society of Mechanical Engineers, involving the relation of the Federation to its member societies, provoked a lengthy and spirited debate. The resolution, as finally adopted, follows:

"Resolved that it shall be the established policy of the Federated American Engineering Societies to advise its member societies promptly and as fully as obligations of confidence will permit of the consideration or undertaking of all matters of material interest and to secure and obtain the advice and counsel of the member societies so far as that can be done without delay or detriment to the matter under consideration."

An encouraging report on the "F. A. E. S. Bulletin" was made by the chairman of the Committee on Publicity and Publications. It was the general feeling of the members of the Council that the "Bulletin" was performing a valuable function and that its influence should be enlarged. James T. Grady of New York was reelected Publicity Director.

A report of the Committee on Engineering Ideals, expressing the desire of the Federation to bring to the attention of the engineering colleges throughout the country the need of pointing engineers toward leadership in public affairs, was adopted. The committee was headed by Prof. Joseph W. Roe of New York University. The Council adopted the report of its Patents Committee requesting "that a Joint Commission be appointed by the Senate and House of Representatives to investigate the needs of the Patent Office, both as to personnel and physical equipment and that it be requested to report at any early date, so that the present session of Congress may take appropriate action."

At the suggestion of the Spokane Engineers Club, transmitted through J. C. Ralston, the Council voted to refer to its Committee on Public Affairs with its endorsement a proposal to recommend to President Harding the selection of "the engineering type of man" as Secretary of the Interior to succeed Mr. Fall, who has resigned. J. Parke Channing, head of the Committee, supported this proposal, saying that it was in keeping with the engineering movement to establish a Department of Public Works. Eighty per cent of the activities of the Interior Department, it was asserted, concerned engineering problems. The speakers made it plain that no political considerations were involved.

The Council passed a resolution submitted by its Committee on Federal Water Power recommending that the Federal Water Power Act of 1920 be amended to provide a permanent adequate and trained personnel. Another suggested amendment provides "that permits or rights of way heretofore granted, or any authority heretofore given pursuant to law, for the purpose of developing, transmitting or utilizing power developed in any of the navigable waters of the United States or upon any of the public lands or reservations of the United States, the administration of such permit, right of way or authority shall rest exclusively in the Commission."

The closing session of the Council was marked by a discussion of the general relation of economics to engineering and of the extent of engineering participation in public matters. A statement of elemental economic considerations prepared by Charles R. Gow of Boston was referred to the Executive Board.

Vice-presidents were elected by the Council as follows: J. Parke Channing and Calvert Townley, New York; Philip N. Moore, St. Louis; Gardner S. Williams, Grand Rapids, Mich. H. E. Howe of Washington was elected treasurer.

The new Executive Board for 1923 is made up as follows:

American Institute of Electrical Engineers—C. G. Adsit, Atlanta; F. B. Jewett, William McClellan, L. F. Morehouse, New York; Prof. C. F. Scott, Yale University.

American Institute of Mining and Metallurgical Engineers—Galen H. Clevenger, Boston; Charles H. MacDowell, Chicago; Allen H. Rogers, Boston.

American Society of Mechanical Engineers—L. P. Alford, Fred J. Miller, New York; Dean A. M. Greene, Jr., Princeton University; John L. Harrington, Kansas City, Mo.; Dean Perley F. Walker, University of Kansas.

Joint Representation of American Society of Safety Engineers American Society of Agricultural Engineers, Society of Industrial Engineers and American Institute of Chemical Engineers—Morton G. Lloyd, U. S. Bureau of Standards, Washington; S. H. McCrory, U. S. Bureau of Public Roads, Washington; Prof. Joseph W. Roe, New York University.

S. H. McCrory was elected chairman of the Finance Committee. The following regional directors were chosen:

District No. 1—A. E. Lindau, Buffalo, N. Y.
District No. 2—W. H. Hoyt, Duluth.
District No. 3—Charles R. Gow, Boston.
District No. 4—W. J. Fisher, York, Pa.
District No. 5—Erskine Ramsay, Birmingham, Ala.
District No. 6—L. A. Canfield, Des Moines, Iowa.

District No. 7—O. H. Koch, Dallas, Tex.

District No. 8—J. C. Ralston, Spokane, Wash.

It was voted to hold the next meeting of the Executive Board in Cincinnati, Ohio, during the last half of March, the exact date to be fixed later. Selection of Cincinnati followed a discussion in which the members of the Council clearly revealed the general opinion that the Board meetings should, as in the past, be held in different cities. This view, expressed by Gardner S. Williams, was concurred in by L. P. Alford and others, it being felt that regional distribution of Board meetings would tend to foster interest in the Federation.

The annual dinner of the American Engineering Council of the Federated American Engineering Societies held at the Chevy Chase Club, Washington, Thursday evening, January 11. Prince Gelasio Gaetani, new Italian Ambassador to the United States, was the guest of honor and the principal speaker.

The Ambassador, himself an engineer and for thirteen years previous to the war a resident of the United States, said that his principal aim is to strengthen the bonds of friendship and esteem between this country and Italy. Recalling his engineering career in the West following his graduation from the Columbia University School of Mines in 1903, Prince Gaetani said that he was returning not only as a diplomat but as an engineer and friend of America.

Engineering, he continued, was destined to play a powerful role in modern civilization. Italy he described as a nation born again. Its potentialities industrially, he said, were bound to make it a great force in world commerce. The electrical industry especially was making rapid strides and all branches of engineering activity were developing constructive effort, in which Italy's greatest asset was an abundance of efficient labor and in which American capital and machinery were needed.

The Ambassador's address was heard by leading engineers, and public officials from all parts of the country. Dean Mortimer E. Cooley of the University of Michigan, president of the American Engineering Council, presided. Other speakers were Calvin W. Rice of New York, secretary of the American Society of Mechanical Engineers, and John J. Tigert, United States Commissioner of Education.

Mr. Rice, who recently returned from South America, where, accompanying Secretary Hughes and party to the Brazilian Centennial Exposition, he acted as an envoy of the American engineering profession, said that definite steps have been taken to promote Pan-American unity among engineers. Through the efforts of the Department of Commerce, Mr. Rice reported, the idea of standardization was spreading in the South American countries, all of which are contemplating legislation to establish a Standardization Bureau, as recommended by Secretary Hoover.

A permanent organization to carry out the resolutions of the recent International Engineering Congress at Rio de Janeiro has been effected, according to Mr. Rice, who said it was now proposed to call a meeting of the Pan-American nations to develop the dream of a transcontinental railway. He predicted that the engineer would be increasingly influential in bringing about Pan-American solidarity and in the attainment of international peace.

Elmer A. Sperry of New York, reporting upon his mission to Japan, told of the remarkable progress being made by the Japanese in industry and in engineering, saying that even England had come to Tokio to gain new ideas in warship construction. Mr. Sperry described the huge size of the industrial plants and machinery used in Japan as exceeding anything known in the United States. The Japanese people, he said, were keeping the disarmament compact to the letter, while the engineers of Japan were aiming to promote a better international understanding by effecting closer relations with the engineers of other nations.

NATIONAL BOARD FOR JURISDICTIONAL AWARDS

An important hearing of the National Board for Jurisdictional Awards is to be held in Washington, Monday, February 19, at 10 a. m. This hearing will have to do with the consideration of the question as to the jurisdiction of metal trim.

There has been much argument over whether the Carpenters' Union or the Metal Trades' Union has jurisdiction over hanging metal doors, windows, etc. The National Board for Jurisdictional Awards, some months ago, rendered a decision in favor of the metal workers. This decision led to the withdrawal of the Carpenters' Union from the Building Trades Department of the American Federation of Labor. The entire subject has been a matter of much debate and controversy. Manufacturers have disagreed, contractors have, as well as labor; so it is very important that all concerned should bear in mind the hearing to be held on February 19.

At this hearing the National Board for Jurisdictional Awards invites all interested parties to be present, prepared to offer such evidence and testimony and exhibits as may be considered necessary or advisable.

PERSONAL MENTION

Wm. Pestell, Sales Manager of the Riley Stoker Co., now has his headquarters in Worcester, Mass.

Roy Kegerreis, formerly of Ann Arbor, Mich., has recently been appointed Physicist at the Mayo Clinic, Rochester, Minn.

R. L. Cornell has severed his connection with the Holt Electric Co., where he was general manager, and is now a member of the firm of Cornell-Mathews Co., in Orlando, Fla.

Basil Lanphier has recently become connected with the Duquesne Light Co., Pittsburgh, Pa. He was formerly with the Interborough Rapid Transit Co., in New York City.

Frederick W. Walker, until recently with the Milwaukee Northern Railway Co., has accepted a position with the Oliver Typewriter Co., Chicago, Ill.

The firm of Woolfenden, Wood & Weber has been changed to Wood & Weber on account of the removal of Mr. Woolfenden to Detroit, Mich., where he has taken charge of other interests.

Lorimer D. Miller, formerly Sales Engineer with the International Motor Co., New York City, is now District Sales Manager of Colodial Inc., Philadelphia, Pa.

E. A. Hanff, formerly electrical engineer with Pittsburgh Electric Furnace Corporation, is now associated with the electric furnace department of William Swindell & Bros., Pittsburgh, Pa.

M. R. Daly, until recently with the W. S. Barstow Management Association, Inc., is now connected with the Pennsylvania Edison Co., Easton, Pa.

W. H. Rudisill, who has been until recently with the Richmond Light & Railroad Company, has joined the force of the Manilla Electric Company, Manilla, P. I.

Charles H. Keel, patent lawyer, has removed his office from the Singer Building to the Bar Building, 36 W. 44th St., New York, in association with Richard Eyre.

Lt. Commander P. L. Carrol, U. S. N., who has been attached to the Bureau of Navigation, Navy Department, Washington, D. C., has been transferred to the U. S. Naval Commission to Brazil.

T. S. Burns, recently connected with the Electric Traction Dept. of the New York Central Railroad, is now Reporting Engineer of the Power Corporation of New York, at Watertown, N. Y.

A. H. Gurtner has severed his connection with the Adirondack Power & Light Co., and has accepted a position with the Brooklyn Edison Company in the designing engineering department.

Jerome Blaisdell has resigned from the Depew & Lancaster Light, Power & Conduit Co. at Lancaster, N. Y. and is associated with the Central Michigan Light & Power Company, at Alma, Mich.

Robert Sibley, Vice-President of A. I. E. E. representing the Pacific District, has resigned his position with the McGraw-Hill Company to become executive manager of the University of California Alumni Association. Mr. Sibley is a graduate and a former member of the faculty of the University of California. For several years past Mr. Sibley has been editor and more recently editorial director of the *Journal of Electricity and Western Industry* and Pacific Coast editorial director of the *Electrical World* and *Electrical Merchandising*. He will continue his connection with these publications in a consulting capacity.

NATIONAL RESEARCH COUNCIL

COOPERATIVE EFFORT TO SOLVE WELDED RAIL JOINT PROBLEMS

The American Electric Railway Association and the American Welding Society with the National Research Council, have united in an authoritative investigation on various types of welded rail joints in commercial use. A Committee on Welded Rail Joints was organized early in 1922, has developed a program, secured financial support, and has experimental work well started on a large scale.

The solution of the problems involved requires cooperation on a large scale. Electric railway companies all over the country are installing thousands of joints every year, in many cases using methods and variations in processes which have been tried elsewhere and found unsatisfactory, or the ultimate effects of which are entirely unknown.

Following a plan adopted by National Research Council in attacking other problems, a committee was organized including members from electric railway companies, rail and equipment manufacturers, and technical laboratories. The aims of the committee are: 1. To determine the present state of the art, 2. To improve upon existing practises by the aid of all obtainable knowledge of the subject, 3. By carefully directed scientific tests and experiments to learn the best way of making each type of welded rail joint. In order to compile a summary of the present state of the art a questionnaire was prepared on the four types of joints in commercial use. Answers to the questionnaire were correlated and a progress report of 73 pages printed.

The work outlined in the program developed by the Committee will involve a sum of the order of $80,000. Cooperation has been offered from all sides; the rail manufacturers will furnish rail for testing purposes, electric railway companies and rail joint manufacturers will furnish joints for testing, the U. S. Bureau of Standards, Purdue University, and University of Illinois will supply laboratory facilities.

Obituary

Dwight C. Rockwood, Associate A. I. E. E., died January 1, 1923. He was born and received his preparatory education in Buffalo, N. Y. He attended Cornell University, from which he graduated in Electrical Engineering in 1899. After graduation he took a three years' apprentice course in the shops of the Westinghouse Electric & Manufacturing Co. In 1905 he entered the employ of the Rochester Gas & Electric Corporation, where he did valuable work until the time of his death.

Engineering Societies Library

The library is a cooperative activity of the American Institute of Electrical Engineers, the American Society of Civil Engineers, the American Institute of Mining and Metallurgical Engineers and the American Society of Mechanical Engineers. It is administered for these Founder Societies by the United Engineering Society, as a public reference library of engineering and the allied sciences. It contains 150,000 volumes and pamphlets and receives currently most of the important periodicals in its field. It is housed in the Engineering Societies Building, 29 West Thirty-ninth St., New York.

In order to place the resources of the Library at the disposal of those unable to visit it in person, the Library is prepared to furnish lists of references to engineering subjects, copies or translations of articles, and similar assistance. Charges sufficient to cover the cost of this work are made.

The Director of the Library will gladly give information concerning charges for the various kinds of service to those interested. In asking for information, letters should be made as definite as possible, so that the investigator may understand clearly what is desired.

The library is open from 9 a. m. to 10 p. m. on all week days except holidays throughout the year except during July and August when the hours are 9 a. m. to 6 p. m.

BOOK NOTICES DECEMBER 1-31, 1922.

Unless otherwise specified, books in this list have been presented by the publishers. The Society does not assume responsibility for any statements made; these are taken from the preface or the text of the book.

All the books listed may be consulted in the Engineering Societies Library.

Elektrotechnik. Pt. 2, Die Gleichstromtechnik; Pt. 3, Die Wechselstromtechnik. By J. Herrmann.

Berlin und Leipzig, Vereinigung Wissenschaftlicher Verleger. (Walter de Gruyter & Co.), 1922, 2 v., illus., diagrs., 6 x 4 in., boards. $.30 each.

By eliminating non-essentials and matter having only historic interest, Professor Herrmann has succeeded in presenting a good account of current practise in direct and alternating-current engineering in these two small volumes. The books are clearly and simply written, give a comprehensive, though necessarily sketchy, view of the field and pay special attention to underlying theory.

La Force Motrice Electrique Dans L'Industrie.

By Eugéne Marec. Paris, Gauthier-Villars et Cie., 1922. 613 pp., illus., diagrs., 10 x 7 in., paper. 55 fr.

A practical treatise for engineers interested in the industrial application of electric power. Intended to explain the fundamental characteristics of commercial electric machines, in order to facilitate the choice of proper equipment, and to explain how this equipment should be installed, operated and maintained. Includes descriptions of accessory machinery and equipment, and shows many examples of the application of motor drive to various classes of machinery.

Incandescent Lighting.

By S. I. Levy. Lond., Isaac Pitman & Sons, [1922]. (Pitman's Common commodities and industries). 129 pp., illus., 7 x 5 in., cloth. $1.00.

After a review of the development of artificial lighting, the author proceeds to describe the development of incandescent lighting by von Welsbach, the rare earth industry and the manufacture of incandescent mantles. The final chapters compare modern methods of lighting and discuss lighting and the energy problem. Attention has been given primarily to the mining and treatment of monazite and to mantle manufacture, but the book brings the whole subject under review in a concise way.

La Radiotelephonie.

By Carle Toché. Paris, Gauthier-Villars et Cie., 1922. 98 pp., illus., diagrs., 9 x 7 in., paper. 10 fr.

A description of the principles of radiotelephony, of the methods and apparatus used for sending and receiving, together with a discussion of its possibilities and its applications. Intended for the general public, as well as for engineers, and written to serve as an introduction to the subject.

MODERN RADIO OPERATION.

By J. O. Smith. N. Y., Wireless Press, 1922. 138 pp., illus., 9 x 6 in., cloth. $1.75.

A popular, non-mathematical description of present methods and apparatus for transmitting and receiving messages by radio-telephone, intended for use by amateurs.

RAILWAY-SIGNALING; AUTOMATIC.

By Fras. Raynar Wilson. Lond., Isaac Pitman & Sons, 1922. (Pitman's technical primers). 116 pp., illus., 7 x 4 in., cloth. $.85.

This small volume is intended to give some particulars of the different methods adopted by railroads and signal manufacturers to provide safe, efficient automatic signaling.

TECHNISCHE SCHWINGUNGSLEHRE.

By Wilhelm Hort. 2d edition. Berlin, Julius Springer, 1922. 828 pp., illus., diagrs., 8 x 5 in., cloth. $4.80.

The author has undertaken to collect and present in systematic fashion our knowledge concerning vibratory phenomena of technical importance. The book covers the mechanics of rigid, elastic, liquid and gaseous bodies in the field of electricity. Methods for investigating these phenomena are given, with examples taken from practise. An extensive bibliography is included.

THEORETISCHE PHYSIK, III: ELEKTRIZITAT UND MAGNETISMUS.

By Gustav Jäger. Berlin u. Leipzig, Vereinigung Wissenschaftlicher Verleger (Walter de Gruyter & Co.), 1922. 140 pp., 6 x 4 in., boards. $.30.

A concise account of electrostatics, magnetism and electromagnetism. This edition differs from its predecessors by the correction of typographical errors, increased condensation and the rewriting of various parts, as well as by various additions.

Addresses Wanted

A list of members whose mail has been returned by the Postal Authorities is given below, together with the addresses as they now appear on the Institute records. Any member knowing the present address of any of these members is requested to communicate with the Secretary at 33 West 39th Street.

1.—Alvaro Daza, Westinghouse International Co., Royal Bk. of Canada Bldg., Havana, Cuba.

2.—William R. Dwyer, 134 N. Lowell Avenue, Syracuse, New York.

3.—Edward J. Ford, P. O. 303, E. Pittsburgh, Penna.

4.—Charles H. Hollenbeck, 7 Virginia Ave., West Orange, New Jersey.

5.—J. M. Mercer, Bristol House, Holburn Viaduct, London, E. C., England.

6.—Robert W. Merritt, 845 So. Gramercy Place, Los Angeles, Calif.

7.—Thomas H. Parker, 1839 Tulare St., Fresno, Calif.

8.—Geo. P. Portjoie, National Farming Mach. Ltd., Montmagny, P. Q., Canada.

9.—J. M. Quinlan, 269 Beach Walk, Honolulu, T. H.

10—J. T. Welsh, 1712 Union Street, Schenectady, N. Y.

Past Section and Branch Meetings

PAST SECTION MEETINGS

Akron.—December 15, 1922. Subject: "Advance in High Potential Insulator Design." Speaker: Mr. A. O. Austin. Attendance 200.

Baltimore.—December 15, 1922. Subject: "Wharfs and Piers with Special Reference to Labor Saving Machinery." Speaker: Mr. W. W. Pagon. Attendance 21.

Boston.—December 12, 1922. Subject: "Engineering and Commercial Standardization." Speaker: Dr. Paul G. Agnew. Attendance 59.

Cincinnati.—December 13, 1922. Subject: "Surges on Power Systems." Speaker: Dr. J. Slepian. Attendance 35.

Cleveland.—December 5, 1922. Subject: "Welding by the Use of Oxy-acetylene Process." Speaker: Mr. S. W. Miller. Attendance 150.

Connecticut.—December 11, 1922. Subject: "Electrify America." Speaker: Mr. M. H. Aylesworth. Attendance 150.

Erie.—December 19, 1922. Subject: "Principles of Radio Communication." Speaker: Mr. P. H. Kroeger, Radio Engineer with the Radio Corporation of America. Attendance 24.

Indianapolis-Lafayette.—December 20, 1922. Subject: "Radio." Speaker: Mr. Francis F. Hamilton. Attendance 47.

Ithaca.—December 14, 1922. Subject: "The Niagara Power Development." Speaker: Mr. J. L. Harper. Attendance 150.

Kansas City.—December 14, 1922. Subject: "Theory of Ionization." Speaker: Prof. Wildish. Attendance 18.

Lehigh Valley.—December 14, 1922. Subject: "Electric Shovels." Speaker: Mr. P. S. Stevens. Attendance 43.

Los Angeles.—November 21, 1922. Subject: "Automatic Substations." Speaker: Mr. Julian Adams. Mr. Cook of the Pacific Electric Railway presented lantern slides of a number of that company's substations. Attendance 50.

Lynn.—December 6, 1922. Subject: "Precision a World Necessity." Speaker: Mr. Charles H. Norton. Attendance 170.

December 20, 1922. Subject: "Application of Electric Wave Filters." Speaker: Mr. K. S. Johnson. Attendance 200.

Madison, Wis.—December 12, 1922. Subject: "Electrification of Railways." Speaker: Prof. J. T. Rood. Attendance 62.

Minnesota.—December 4, 1922. Subject: "Some New Developments in Electrical Measuring Instruments." Speaker: Mr. D. J. Angus. Attendance 85.

New York.—On January 19, 1923 the New York Section held its most successful meeting of the year in the auditorium of the Engineering Societies Building. Dr. M. I. Pupin, Professor of Electro-Mechanics at Columbia University was the speaker of the evening. His subject "The Story of Electron Physics" proved an effective drawing card as the attendance was about 650. Dr. Pupin followed the development of the theory of electricity and magnetism from the work of Faraday and Maxwell down to the present time, including Einstein's "Theory of Relativity" which theory, should it be substantiated by the results of recent tests, he stated would be the second great step in the development of Faraday's work.

Pittsburgh.—December 12, 1922. Subject: "Lightning Arresters." Speaker: Mr. Denny W. Roper. Attendance 306.

January 9, 1923. Subject: "Design of A-C. Substations." Speaker: Mr. A. H. Kehoe. Attendance 248.

Pittsfield.—December 5, 1922. Subject: "In Unknown Baffin Land." Speaker: Capt. Donald B. MacMillan. Attendance 850.

Portland.—December 19, 1922. Subject: "High-Voltage Phenomena and the Porcelain Insulator." Speaker: Mr. W. A. Hillebrand. Attendance 80.

Providence.—December 19, 1922. "The Relationship of the Navy and the Merchant Marine." Speaker: Rear Admiral W. S. Sims. Attendance 500.

January 5, 1923. Joint meeting of the Providence Section and the Power Section of the Providence Engineering Society. Subject: "The Power Factor Problem in Industrial Plants." Speaker: Mr. H. E. Dralle. The paper was prepared by Mr. W. C. Drake.

St. Louis.—December 20, 1922. Business meeting. Attendance 23.

San Francisco.—December 6, 1922. Subject: "Carrier Current Telephone and Telegraph Systems." Speaker: Mr. H. W. Hitchcock. Attendance 110.

Schenectady.—December 15, 1922. Subject: "The Engineers Editor." Speaker: Mr. Harold V. Bosell. Attendance 40.

Springfield.—December 15, 1922. Subject: "Recent Developments in the Design of Transmission Systems." Speaker: Mr. H. W. Dewey. Attendance 28.

Syracuse.—November 24, 1922. Subject: "The Story of an Electric Meter," shown by a representative of the Sangamo Electric Co. Attendance 35.

Urbana.—December 12, 1922. Motion pictures were shown illustrating the manufacture of Ford automobiles. Attendance 250.

Vancouver.—December 8, 1922. Subject: "Underground Railways." Speaker: Mr. H. R. Smith. Attendance 32.

Washington, D. C.—December 12, 1922. Subject: "Recent Developments in Electric Meters." Speaker: Mr. F. C. Holtz. Attendance 79.

Worcester.—Subject: "Vacuum Tubes." Speaker: Mr. H. H. Newell. Attendance 103.

PAST BRANCH MEETINGS

University of Alabama.—December 13, 1922. Business meeting. Attendance 15.

University of Arizona.—December 13, 1922. Business meeting, followed by a discussion of storage batteries by Mr. Wray. A moving picture entitled "Thunder Bolts" was shown. Attendance 26.

Armour Institute of Technology.—January 11, 1923. Subject: "X-Rays." Speaker: Mr. Morrison of the Acme X-ray Co. Attendance 78.

Brooklyn Polytechnic Institute.—December 15, 1922. Subject: "High-Power Vacuum Tubes." Speaker: Dr. M. J. Kelly of the Western Electric Co.; student speakers were Messrs. J. Loerch on "Electrical Adhesion" and J. Leibowitz on "Amplifiers." Attendance 75.

University of California.—November 29, 1922. Business meeting and motion pictures "The King of the Rail" and "The Oil Industry in Mexico." Attendance 58.

Carnegie Institute of Technology.—December 12, 1922. Subject: "Lightning Arresters." Speaker: Mr. Denny W. Roper. Attendance 300.

Case School of Applied Science.—Subject: "The Engineer in Business." Speaker: Mr. W. M. Skiff. Attendance 42.

Kansas State College.—December 11, 1922. Subjects: "Traffic Congestion and Safety Devices on Street Cars," by Mr. E. L. Misegades, and "Elevated Lines," by Mr. R. H. Peters. Attendance 83.

Lehigh University.—January 9, 1923. Subject: "Electric Welding." Speaker: Mr. H. E. Dralle of the Westinghouse Electric & Mfg. Co. The talk was accompanied by slides. Attendance 45.

Lewis Institute.—December 8, 1922. Inspection trip to plant of American Tel. & Tel. Co. Attendance 30.

December 13, 1922. Business meeting. Attendance 16.

University of Maine.—November 29, 1922. Subject: "Meters and Meter Development." Speaker: Mr. E. K. Brown, of the General Electric Co. Attendance 40.

Marquette University.—December 14, 1922. Subject: "Stroboscopic Method of Speed Measurement," by Mr. H. E. Degentesh, and "Some Theories on Repulsion-Induction Motors" by Dr. John F. M. Douglas. Attendance 31.

Michigan Agricultural College.—December 12, 1922. Subjects: "Power Companies and Transmission Systems," by Mr. H. J. Burton, and "Company Morale and Cooperation. Attendance 31.

University of Michigan.—December 8, 1922. Joint meeting of the Detroit-Ann Arbor and Student Branch. Subject: "The Economic Significance of Simultaneous Telephony and Telegraphy." Speaker: Mr. R. D. Parker. Attendance 90.

University of Missouri.—November 22, 1922. Subject: "The Relation of the Engineering Profession to National Economic Development." Speaker: Mr. Paul Howard. Attendance 26.

December 6, 1922. Subject: "Multiplex Telephony." Speaker: Mr. Nelson Nebel. Mr. Barnes of the General Electric Co. gave a talk on the student engineers course at that company. Attendance 11.

University of Nebraska.—December 13, 1922. Dean O. J. Ferguson spoke on the course of study and the relations existing between the various subjects required of electrical engineering students. Prof. O. E. Edison spoke briefly on the history of the electrical engineering building. Attendance 93.

University of North Dakota.—December 18, 1922. Subject: "The Fundamental Principles of Radio Telephony." Speaker: Prof. C. W. Byers. Attendance 42.

University of Notre Dame.—December 11, 1922. Subjects: "Rectifiers," by Mr. Cyril Birkhead and "Mathematical Fallacies," by Mr. R. E. Cordray. Attendance 44.

Ohio Northern University.—January 11, 1923. Moving pictures were shown: "The Spirit of Progress" and "The Use of Compressed Air."

Oklahoma A. & M.—December 7, 1922. Business meeting. Attendance 22.

Oklahoma University.—December 7, 1922. Subjects: "One Million Volt Transformer," by Mr. W. Reilly, and "Transmission Relays," by Mr. C. Rousch. Attendance 20.

Purdue University.—January 10, 1923. Subject: "Employment and Handling of Men," by Mr. J. W. De Cou. Attendance 25.

Rensselaer.—December 19, 1922. Subject: "Magnetism." Speaker: Mr. L. T. Robinson of the General Electric Co. Attendance 225.

University of Southern California.—December 13, 1922. Subject: "High Line Protection Devices." Speaker: Mr. Loyad Hunt. Attendance 18.

Stanford University.—January 5, 1923. Business meeting. Attendance 15.

Swarthmore.—November 10, 1922. Illustrated lecture "Tarvia Roads." November 17, 1922 Subject: "Chippewa-Queenston Project." Speakers: Messrs. W. N. Landis and K. J. L. Swyler.

November 24, 1922. Illustrated lecture "Concrete Highways," by a representative of the Atlas Cement Co.

December 8, 1922. Subject: "Vacuum Tubes," by Messrs. A. J. Williams and T. S. Oliver.

December 15, 1922. Joint meeting with the Philadelphia Section of the A. S. M. E. Attendance 150.

January 5, 1923. Business meeting.

January 11, 1923. Illustrated lecture "Down the McKenzie," by Mr. Fullerton Waldo. Attendance 200.

Syracuse University.—December 7, 1922. Subject: "Operating Faults of Alternating-Current Motors." Speaker: Mr. Clifford Williams. Attendance 19.

December 14, 1922. Subjects: "Electrical Distribution to Small Consumers," by Mr. L. F. Angwin and "Elevator Signal Systems," by Mr. Sidney Maunder. Attendance 19.

Texas A. & M. College.—October 31, 1922. Subjects: "The Lubrication of Elevators," by Mr. W. M. Kimbrough, and "Power Afloat," by G. A. Hollowell.

November 14, 1922. Subjects: "Electrical Operation of Railways in Mountainous Districts," by Mr. W. F. Adams,

"Bearings," by Mr. F. C. Simmons and "The First Central Station," by Mr. D. P. Richardson.

November 28, 1922. Subjects: "Radio Photography," by Mr. H. H. Carroll, and "The High Intensity Motion Picture Arc," by Mr. R. F. Reid.

December 12, 1922. Subjects: "Electric Lighting of Railway Cars," by Mr. G. Clement and "Flexible Cords for Electrical Appliances," by Mr. A. C. Rogers.

January 8, 1922. A technical moving picture was shown, entitled "Behind the Button." Papers read were: "Automatic Hydroelectric Plants," by Mr. T. L. Jones, and "The Noiseless Turbine," by Mr. W. D. Morrow.

Washington State College.—December 18, 1922. Subject: "The Super-Power Project." Speaker: Mr. Hoeple. Attendance 34.

University of Washington.—November 7, 1922. Subject: "The Progress of the City Light Plant at Tacoma, Wash." Speaker: Mr. Luelwyn Evans. Attendance 48.

December 7, 1922. Subject: "Illuminating Problems." Speaker: Mr. L. V. Morgan, of the Western Electric Co.

West Virginia University.—December 18, 1922. A number of papers were presented on electrical engineering subjects by Messrs. C. E. Hutcheson, L. G. Porter, W. D. Stump, A. Winter, T. Forman, Guy A. Moffett, C. W. Addis, J. Copley, G. C. Pugh, L. T. Faulkner and R. Lee. Attendance 30.

Employment Service Bulletin

OPPORTUNITIES.—Desirable opportunities for service from responsible sources are announced in this Bulletin, and no charge therefor is made.

MEN AVAILABLE.—Under this heading brief announcements will be publishedwithout charge to the members. Announcements will not be repeated except upon request received after a period of three months, during which period names and records will remain in the active files.

NOTE.—Notices for the JOURNAL ***should be addressed to EMPLOYMENT SERVICE, 33 West 39th Street, New York, N. Y.,*** *the employment clearing house of the National Societies of Civil, Mechanical, Mining and Electrical Engineers.*

Notices for the JOURNAL are not acknowledged by personal letter, but if received prior to the 16th of the month will appear in the issue of the following month.

All replies to either "Opportunities" or "Services Available" should be addressed to the key number indicated in each case ***and forwarded to EMPLOYMENT SERVICE,*** *as above.*

Replies received by the bureau after the position to which they refer has been filled will not be forwarded, and will be held by the bureau for one month only.

OPPORTUNITIES

PARTNER with engineering ability ready to invest minimum of $35,000, part of which may be paid from earnings, desired for long established prosperous business in special machinery. Founder of the business unable to properly care for present organization and expansion. V-3098.

MECHANICAL & POWER ENGINEER, experienced in power plant practise, operation, calculations, utilization and departmental distribution of power, steam, water, coal, etc. in large manufacturing plant located in Wisconsin. Application by letter stating age and salary expected, experience in detail. V-3105.

ELECTRICAL ENGINEER. Technical graduate with experience in design and inspection of overhead and underground electrical distribution and transmission systems, substation and steam electric generating stations in the engineering dept. of large public utility. Also, structural engineer with experience in design and construction of reinforced concrete and other structures. Application by letter. Salary not stated. Location, Texas. V-3140.

TECHNICAL GRADUATE, preferably electrical who has had considerable experience on design and layout of electrical apparatus in electric power houses. Experience in electrical transmission work, although not absolutely essential, will be valuable. Work will embrace interior layout of electrical apparatus on proposed new power plants and substations. Application by letter. Salary will depend on qualifications, including initiative and possibilities of development. Location, New York State. V-3141.

STRUCTURAL ENGINEER with experience in design and construction of reinforced concrete and other structures for public utilities. Application by letter. Salary not stated. Location, Texas. V-3153.

G. E. GRADUATE, 2 years practical experience since leaving college to work in municipal design office on water works. Must be resident of N. J. Application by letter stating age, education and experience. Salary $2100. Location, N. J. V-3157.

FIRST CLASS DRAFTSMAN on water supply work and civil engineering drawings, rapid work and first class tracer. Must be resident of N. J. Application by letter stating age, education and experience. Salary $2400. Location, N. J. V-3158.

ROOFING MATERIALS SALES ENGINEER. Previous selling experience in roofing trade important. Excellent opportunity for man with automobile and above requirement to obtain part interest in good business. Application by letter. Salary not stated. Location, New York City. V-3161.

ELECTRICAL DRAFTSMAN for power house and substation layout work. Application in person. Salary not stated. Location, New York City. V-3184.

DRAFTSMAN with signal circuit layout and relay protection work experience. Application in person. Salary not stated. Location, New York City. V-3185.

ENGINEER experienced in the application and sale of high grade electric power equipment. Must be hustler and willing to start on commission. Application by letter. Headquarters, New York City. V-3315.

STRUCTURAL STEEL DETAILERS, CHECKERS, DESIGNERS, etc. Application by letter. Salary not stated. Location, Connecticut. V-3317.

ENGINEERS with experience in management organization to investigate public service, state and city departments. Must be able to secure facts and figures by which to measure output against cost. Application by letter. Salary not stated. Location, Middle West. V-3321.

ELECTRICAL ENGINEER with experience on power plant electrical equipment, substation and transmission lines for construction design work and technical problems connected with the operation of a large public utility system. Technical experience together with experience on similar work necessary. Application by letter giving details of education, experience, personal characteristics, references and salary desired. Salary not stated. Location, West Virginia. V-3324. (Send photograph if possible.)

HIGH CLASS ELECTRICAL SALES REPRESENTATIVES wanted by manufacturers of carbon, graphite, electro-graphitic and metallic brushes for motors and generators; also general line of carbon specialties. Exclusive rights given to each of territories on liberal straight commission sales proposition. Specify in detail past engineering and sales experience. Application by letter. Salary not stated. Location, N. Y. State. V-3338.

MAN capable of original designing for underground distribution systems. Salary not stated. Application by letter. Location, Ohio. V-3341.

ENGINEER as head of meter dept. Must have had practical experience with all types of meters. Application in person. Salary $250. Location, Cuba. V-3344.

YOUNG SALES ENGINEER for company manufacturing electrical heating appliances and wireless apparatus. Must have a pleasing personality. Experience unnecessary. Only young man will be considered. Application in person. Salary and commission. Location, N. Y. C. and northern N. J. V-3346.

A large central station in New York City requires services of a recent technical graduate to assist on general power plant test work and instrument maintenance work. Although work at first will be quite elementary, it is desired that applicant should possess a thorough technical knowledge and should also possess initiative, tact and a pleasing personality, in order to be in line for promotion when such an opportunity arrived. Application by letter. V-3363.

GENERAL SALES MANAGER for corporation. Man between 35-40 years of age, who is well versed in power plant equipment. Desire man of great strength of character. Application by letter. Salary not stated. Headquarters, Ohio. V-3367.

MAN to qualify as sales manager of company. Must be an engineer with knowledge of central station industry and knowledge of advertising. Interview January 8th at Engineering Soc. Bldg. Headquarters, New York City. Salary not stated. V-3387.

MECHANICAL AND ELECTRICAL DRAFTSMAN experienced in motor device gearing, reduction gears and general machine tool design. Married man to live in Connecticut. Application by letter enclosing samples of detail

work and tracing. Salary not stated. Location, Conn. V-3392.

ELECTRICAL ENGINEER with a few years experience in design industrial plant layout, as well as handling of field construction work in connection with same. Application by letter. Salary not stated. Location, Illinois. V-3393.

ELECTRICAL DRAFTSMAN familiar with hydroelectric work. Single man speaking Spanish preferred. Application in person. Location, Peru. R-19.

SALES ENGINEER to sell carbon products including motor brushes, arc and welding carbons, etc. May be located in any part of the country. Application by letter. Salary not stated. Headquarters, Ohio. R-51.

DRAFTSMAN. Large manufacturer in N. Y. C. has an opening for a man with experience in connection diagrams of a-c. and d-c. switchboards. Permanent position. Application by letter giving full details of experience and salary expected. Location, N. Y. C. R-52.

POWER HOUSE DESIGNER, must be familiar with steam turbine electric generating station layout and condenser systems. Do not want high class engineer but require good designing draftsman familiar with work mentioned. Application by letter. Location, Arizona. R-57.

MAN about 28 years of age for time study work. Must have had experience in woodworking plant. Prefer one with technical education. Application by letter stating experience, references, and salary expected. Location, Wisconsin. R-58.

ELECTRICAL DRAFTSMAN, technical graduate preferred, experienced in substation and transmission line design, motor application and control. Some knowledge of mining desirable but not essential. Application by letter stating age, experience in detail, salary expected and when available. Location, Eastern Pa. R-72.

ENERGETIC YOUNG MAN, wide awake, who has had some experience in the manufacture and sale of electrical instruments. Application by letter. Salary not stated. Location, Pennsylvania. R-73.

TIME AND JOB ANALYST wanted on manufacture of electrical apparatus. Prefer technical graduate with 2-3 years first hand shop experience, not necessarily in electrical industry. Application by letter. Salary not stated. Location, Mass. R-122.

MEN (2), to act as its representatives in greater N. Y. on a commission basis, to sell their sash chain to building contractors and architects. Would like to secure men who have established connections. Application by letter. Headquarters, Connecticut. R-124.

ENGINEER HYDROELECTRIC MATURE MAN experienced in power plant design and hydraulics. Application by letter. Salary not stated. Location, Illinois. R-133.

PRODUCTION ENGINEER with metal and woodwork experience on refrigerators. This experience necessary. Application by letter stating age, education and experience. Location not stated. Salary not stated. R-153.

CLERK in Motor Repair Dept. to keep records of motors, coming in and going out of shop; records of material and time on the jobs, etc. Technical knowledge of motors and generators would be desirable, as job offers opportunities for advancement. Resident of Newark, N. J. desired. Application by letter. R-156.

MECHANICAL MAINTENANCE MEN for work at mine and mill sites. Knowledge of Spanish and some technical training preferred. Application by letter. Salary not stated. Location Phila. R-161.

BETTERMENT ENGINEER, technical graduate with 5 years' operating experience needed in conjunction with betterment work of public utility plants in Cuba and Panama. Must be capable of analyzing plant operation and troubles, recommending and carrying to conclusion suggested improvements. Must be well grounded in thermodynamics, combustion of oil and general operation of turbines, condensers and auxiliaries. Knowledge of Diesel engines necessary and refrigeration desirable. Spanish helpful, but not necessary. Application by letter giving full history, education and experience. State nationality, age, present and expected salary. R-169.

STEAM PLANT SUPERINTENDENT. Want high grade technical graduate who has had direct experience in supervision and operation of public utility steam electric station. Must have executive ability and be capable of handling men. Expect opening near future. A superintendent of power in charge of transmission system and plants for superintendent of steam station having 45,000 kv. installed. Location, center and southwest. Man experienced in handling up-to-date equipment and capable maintaining in equipment and economical operation desired. Application by letter giving full detail, education and experience. State nationality, age, references and salary desired. R-170.

ELECTRICAL DRAFTSMAN experienced in designing high and low-tension work for power stations and substations. Application by letter. Location, Penn. R-175.

ELECTRICAL DESIGNER. Thoroughly experienced with high and low-tension power plant apparatus, to design arrangement of equipment for indoor and outdoor substations, switching apparatus, etc. Want electrical engineer with at least 10 years' experience with power plant work and able to supervise drafting room force. Application by letter. Location, Penn. R-176.

MEN AVAILABLE

ELECTRICAL AND MECHANICAL SUPERVISOR: Experience: operation, maintenance, and construction of power plants, substations, transmission and distribution systems; twelve years practical experience of which nine years was in foreign countries. Speaks Spanish fluently, understands Portuguese and Italian. Available for foreign or domestic service, available Jan. 1st. E-4123.

EXECUTIVE ENGINEER SECRETARY—B. S., E. E. Univ. of Wis., (with honors), Has directed entire organization, seven years experience hydroelectric, paper manufacturing and general construction work. Age 28. Single. Will consider $4000 and opportunity. E-4124.

ELECTRIC RAILWAY ENGINEER has 20 years engineering, business and executive experience to offer to an engineering firm or public utility in or near either New York, Philadelphia or Boston. E-4125.

ELECTRICAL ENGINEER, interested in design of electrical apparatus, capable of doing original developmental work. Age 25. Four years experience since graduation, including sales and high grade developmental work. E-4126.

ELECTRICAL ENGINEER AND EXECUTIVE, now employed, wishes to make change. Seven years experience in field and office work, two years G. E. test. Assoc. A. I. E. E. Capable of designing and laying out work. Desires position with some manufacturer of railway electrical equipment or automatic machinery. E-4127.

ELECTRICAL ENGINEERING STUDENT in the 4th year of a night course, age 23, 5 years experience in mechanical drafting, desires position with electrical concern in New York City, preferably as draftsman but will consider any other position with advancement. E-4128.

ELECTRICAL ENGINEER, technical graduate experienced in telephone installation, equipment, operation and maintenance, desires position affording chance for advancement. Salary not primary object. Specialized on radio problems. Power work considered. E-4129.

MECHANICAL ENGINEER. Fifteen years experience mining, milling and smelting and as sales engineer for mining, power and electrical equipment. Fluent Spanish. At present employed but desires change. Would consider far east. Available after July first, 1923. E-4130.

EXECUTIVE. M. E. 1912, age 34. Experience includes draftsman, electrician, repairs, maintenance, construction, research, purchasing and production manager. Includes electric railway, consulting engineering, cement manufacture and carbon electrode manufacture. Permanent connection with responsibility desired. Available after 30 days notice. Salary $4200. E-4131.

DRAFTSMAN. Age 33, 12 years' experience as marine electrical draftsman desires responsible position. Available on 2 weeks notice. Assoc. A. I. E. E. E-4132.

ELECTRICAL ENGINEER. University graduate, 12 years' experience in estimating, designing and construction of power houses and substations in United States and Europe, good accountant, commercial abilities. Speaks French, German. Going to Europe. Desires connections. E-4133.

GRADUATE ELECTRICAL ENGINEER of R. I. State College, 1923, desires experience in electric railway or telephone work. E-4134.

ENGINEER EXECUTIVE desires situation where he will be more heavily taxed to hold his job. Two years' experience in electric railway construction and maintenance of way, two years as lieutenant, Corps of Engineers, U. S. Army, and three and a half years with the present company, as engineer in charge of scheduling production of radio and similar apparatus. Broad collegiate and engineering education. If you have need of the qualifications enumerated, a personal interview will gladly be arranged. E-4135.

YOUNG MAN with five years experience in radio, operating, testing, maintenance and teaching commercial class, desires permanent connection with large firm. Three years telephone work. E-4136.

YOUNG ELECTRICAL ENGINEER, receiving B. S. degree from the University of California in May, 1923, desires to become connected with some company engaged in hydroelectric power development. Available June 1st. E-4137.

RECENT E. E. GRADUATE, 22 years of age, also B. S. degree, with practical experience in accounting and cost work, desires appointment where advancement will lead to executive position. New York City preferred. E-4138.

ELECTRICAL ENGINEER desires a position with a consulting organization. Broad electrical and business training; ten years of shop, inspection, valuation, and teaching experience in electric railway, power, telephone, and associated work. Age 30 years. E-4139.

ELECTRIC RAILWAY ENGINEER, twenty-five years experience in construction, operation, valuation, investigation of and reporting upon electric railway properties; also traffic studies. Now employed but desires change. Would prefer to connect with a large operating or construction company or with a consulting engineer. Willing to go anywhere. E-4140.

HYDROELECTRIC ENGINEER with eleven years active practise in the design and construction of water-power developments, power plants, substations, and transmission lines. Will consider opening with firm of well established consulting engineers, or position as industrial engineer with large concern. Age 32, married. Speaks Spanish. Two degrees in engineering. State license. Member A. I. E. E. E-4141.

ELECTRICAL ENGINEER graduate, with nine years telephone experience, both executive and engineering work, two years construction work on high tension equipment. Two years manufacturing and sales work. Best of references, hard worker, desire change at once now engaged on sales work and wishes to return to engineering profession. E-4142.

ELECTRICAL ENGINEER, graduate, experienced in design, construction and maintenance of

electrical equipment of plants; desires position with firm of consulting engineers, or as superintendent of electrical construction. Knowledge of Spanish. E-4143.

ELECTRICAL ENGINEER, age 30, married, high grade European education, G. E. Test experience, successful inventor of electrical instruments and machines, with commercial abilities, speaking five languages fluently, willing worker, wants to be sent abroad in responsible position. E-4144.

ELECTRICAL ENGINEER, age 32, married, university technical graduate, associate member A. I. E. E. Six years construction and service on substation and generating station work. Westinghouse graduate course and test floor experience. Desire position with municipal plant, electric railway or electrical contractor in Middle West. E-4145.

PROMINENT SALES ENGINEER. Graduate electrical engineer with test, manufacturing and engineering experience. Has broad acquaintance in eastern section, among street railway companies, electrified steam railroads, power plants, and large manufacturing companies of all kinds. Executive and advertising experience. Wishes position as sales manager or leading to sales manager or an agency for companies manufacturing apparatus of merit. Now located in New York City. E-4146.

ELECTRICAL ENGINEER, B. S., E. E. Assoc. A. I. E. E., married, age 25. Two and one-half years experience in G. E. test and office. Desire connection with public utility company, or engineering and management organization, but will consider any offer with a future. Location in west essential. Now employed. E-4147.

MECHANICAL AND ELECTRICAL ENGINEER, graduate, age 32, with extensive experience in railroad electrification, both design and construction, desires position with railroad about to electrify or consulting engineers. At present in full charge of lines, power plant, automatic substations and rolling stock of electrified line. Change desired for personal reasons. Present salary $6,000.00. Available within reasonable time. Mem. A. I. E. E. E-4148.

ELECTRICAL ENGINEER, age 43, married, technical graduate. Over sixteen years experience in manufacturing, construction and design, specializing in power plants, substations and distribution systems. High and low tension, with largest construction and public utility companies in U. S. A. and abroad. At present employed but desirous of making a change for a position of responsibility. E-4149.

GRADUATE ELECTRICAL ENGINEER, age 37, exceptional inventive ability. Formerly engineer in research laboratory of General Electric Company and with additional broad electrical power and industrial engineering experience desires position as developmental or research engineer competent to attack industrial problems from engineering as well as laboratory standpoint, excellent references. E-4150.

CORNELL ENGINEER, G. E. Test man, four years designing, construction, organizing, operating experience, east and west, terminating three year foreign service with commercial selling house, managerial experience, this summer. Desires new foreign service connections. E-4151.

ERECTING ENGINEER wishes connection with manufacturer of heavy machinery as field erection engineer or with power company as master mechanic on the care of hydroelectric equipment. Age 39, married, 20 years wide experience in this and foreign countries. Associate A. I. E. E. E-4152.

ELECTRICIAN. Twelve years' experience in station operation, construction and industrial plant maintenance, a-c. and d-c. familiar with remote control and switchboard wiring, two years' technical schooling. Married. Age 39. E-4153.

MEMBERSHIP — Applications, Elections, Transfers, Etc.

ASSOCIATES ELECTED JANUARY 17, 1923

ACKERMAN, ORA RANSOM, Checking Draftsman, Commonwealth Edison Co., 72 W. Adams St., Chicago, Ill.

*ADELSBERGER, EZRA, Student, School of Engineering of Milwaukee, 754 Cass Ave., Milwaukee, Wis.

ALBRECHT, HAROLD LOUIS, Engineer, Electrical Regulation & Distribution, Toledo Edison Co., Toledo, Ohio.

*ALMQUIST, MILTON LEROY, Radio Engineer, American Tel. & Tel. Co., 195 Broadway, New York, N. Y.

*ANDERSON, HENRY CHAUNCEY, Associate Western Editor, *Electrical World*, McGraw-Hill Co., 1507 Old Colony Bldg., Chicago, Ill.

*ARTHUR, STANLEY WILLIAM, Telephone Engineer, American Tel. & Tel. Co., 230 E. Grand River Ave., Detroit, Mich.

*AXMAN, ERNEST, Supply Engg. Dept., Westinghouse Electric & Mfg. Co., E. Pittsburgh; res., Wilkinsburg, Pa.

BALDWIN, HOWARD DENTON, Salesman Westinghouse Elec. & Mfg. Co., 1224 Miner's Bank Bldg., Wilkes-Barre, Pa.

*BALL, WILMOT COLES, Graduate Student, Johns Hopkins University, Homewood; res., Baltimore, Md.

BALSBAUGH, JAYSON CLAIR, Assistant, Electrical Engineering Dept., Mass. Inst. of Technology, Cambridge, Mass.

BARAKER, ALEXANDER E., Engineer, 3367 3rd Ave., New York, N. Y.

BARNES, LLOYD ANDRESS, Chief Electrician, Los Alamitos Sugar Co., Los Alamitos, Calif.

BARNUM, STARR H., Vice-President & Secretary, The Bigelow Company, New Haven, Conn.

*BASTON, CYRIL E., Railway Equipment Engineering Dept., Westinghouse Elec. & Mfg. Co., E. Pittsburgh; res., Wilkinsburg, Pa.

*BAUGHMAN, GEORGE WASHINGTON, Jr., Electrical Engineer, Western Electric Co., 463 West St., New York, N. Y.

*BAXTER, WILLIAM JAMES, Engineer, Miniature Engineering Dept., Edison Lamp Works of General Electric Co., Harrison; res., E. Orange, N. J.

BEAR, FREDERIC THOMAS, Engineering Dept., Philadelphia Suburban Gas & Electric Co., Phoenixville; res., Linfield, Penn.

*BENTLEY, EDWARD BELL, Engineer, Commercial Dept., The Springfield Light, Heat & Power Co., Springfield, Ohio.

BETTEX, ALBERT ALEXANDRE, Electrical Draftsman, Brooklyn Edison Co., Brooklyn, N. Y.

BICKFORD, LAWRENCE W., Electrical Draftsman, Gibbs Brothers, Inc.; Newport News, S. B. & D. D. Co., Newport News, Va.

*BISHOP, RAYMOND DOWLEY, Tester, Western Electric Co., Philadelphia, Pa.; res., Camden, N. J.

*BIVINS, DANIEL EUGENE, Jr., Electrical Testing Dept., General Electric Co., 1001 Delamont Ave., Schenectady, N. Y.

BLECKSMITH, ARTHUR FRED, Foreman, Repairing & Testing Electric Meters, Union Gas & Electric Co., Cincinnati, Ohio; res., Dayton, Ky.

BOSS, RALPH ADOLPH, Electrician (Power Work), Potomac Electric Power Co., 920 8th St., N. E., Washington, D. C.

*BOSWAY, JULIUS, Sales Engineer, General Electric Company, Dayton Savings & Trust Bldg., Dayton, Ohio.

*BOURNE, ROLAND BARDEEN, Receiving Engineer, Radio Corp. of America, Chatham, Mass.

BRILL, EDWARD JONAS, System Operator, Pennsylvania Power & Light Co., Hazleton, Pa.

BRIMER, LAURENCE FREDERICK, Electrical Engineer, Distribution Dept., Winnipeg Hydro-Electric Power Co., 55-59 Princess St., Winnipeg, Man.

BROCKHUIJSEN, WILLEM CORNELIS, Inspector, Installation Branch, Western Electric Co., New York, N. Y.

BROSTROM, CARL, Chief Engineer, Campania Peruana de Telefonos Limitada, Lima, Peru, S. A.

BROWN, SAMUEL, 2725 Ocean Parkway, Brooklyn, N. Y.

BROWNELL, GEORGE WILLIAM, Service Man, Potomac Public Service Co., Public Sq., Hagerstown, Md.; res., Waynesboro, Penn.

*BRUSH, WAITE SMITH, District Supervisor, Western Electric Co., Inc., 401 Hudson St., New York; 102 Clinton Ave., Albany, N. Y.

*BRYANT, ROGER HOWARD, Radio Engineering Dept, Westinghouse Electric & Mfg. Co., E. Pittsburgh; res., Wilkinsburg, Pa.

*BUCK, HARLAND H., Engineer, Transmission & Protection Dept., Ohio Bell Telephone Co., 4300 Euclid Ave., Cleveland, Ohio.

*BUDDEN, FRANK WILFRID, Transmission Engineer, Pacific Tel. & Tel. Co., Seattle, Wash.

BUENDIA, LUIS AMABLE, Consulting Engineer, Murrie Engineers, Inc.; Representative, Pan-American Student League; Consul of Ecuador, 17 Battery Place, New York, N. Y.

BURBIDGE, FREDERICK HAROLD, Salesman, Dominion Engineering Agency, 24 Adelaide St. East, Toronto, Ont., Can.

*BURROUGH, EDWARD LEWIS, Engineer, A-G. Mfg. Co., 1350 Dearborn St.; res., 4503 Thackery Place, Seattle, Wash.

*BYER, LESLIE CONWELL, Patent Dept., General Electric Co., 1405 G St., N. W., Washington, D. C.

CABRAL, ANTHONY PADUA, Chief Electrician, A. P. Merchant Co., Inc., 9-11 Avery St., Boston; res., E. Boston, Mass.

CALLAHAN, JOHN L., Radio Engineer, Radio Corporation of America, 233 Broadway, New York, N. Y.

*CARNEY, JOHN T., Long Lines Engineering Dept., American Tel. & Tel. Co., 195 Broadway, New York; res., Brooklyn, N. Y.

CARRADUS, THOMAS WIGHTMAN, Proprietor, Electric Machinery Company, 28 New Union St., Ancoats, Manchester, Eng.

CERNY, FRANK W., Supt., Public Utilities, Town of Mesa City, Mesa, Ariz.

CHAMBERLIN, GEORGE W., Overhead Engineer, Commonwealth Edison Co., 72 W. Adams St., Chicago, Ill.

CHARLESON, EDWARD V., Vice-President & General Manager, Charleson Storage Battery Co., Woodville, Pa.

CHITTERLING, MORRISON PAGE, Engineer, Motor Engineering Dept., River Works, General Electric Co., W. Lynn, Mass.

*COLEMAN, JAMES O'REILLY, Assistant in Electrical Engineering Dept., Mass. Institute of Technology, Cambridge, 39, Mass.

CONESA, JULIO M., Inspector & Tester, Automatic Machine Tel: Switching, Westinghouse Elec. & Mfg. Co., 24 Walker St., New York, N. Y.

COOK, EARL THOMAS, Testing Engineer, Albert F. Ganz, Inc., New York, N. Y.; res., 2311 E. 69th St., Chicago, Ill.

*COOK, ELLSWORTH DEWITT, Student, Union College, Schenectady; res., Scotia, N. Y.

CORWIN, RUDOLPH M., Chief Power House Electrician, The Springfield Light, Heat & Power Co., Springfield, O.

COTE, OMER EUGENE, Chief Engineer, Electrical Products Mfg. Co., Providence, R. I.

COWDREY, JOSEPH E., Manager, Electrical & Wire Rope Dept. also Aerial Tramways, United States Steel Products Co., 30 Church St., New York, N. Y.

CREAGER, JOSEPH IGNATIUS, Installation & Maintenance, Potomac Electric Power Co., Washington, D. C.; res., Mt. Rainier, Md.

*CRIPPEN, REID PERKINS, Asst. Instructor, Electrical Engineering Dept., University of California, Mechanics Bldg., Berkeley, Calif.

CROFTIN, WILLIAM MOORE, Supervisor, Western Electric Co., Inc., 4107 14th Ave., Brooklyn, N. Y.

CROSSE, AUGUSTUS ELLWOOD, Equipment Engineer, The Pacific Tel. & Tel. Co., Telephone Bldg., Seattle, Wash.

CUMMINGS, WALTER JOHN, Substation Operator, Monongahela Power & Railway Co., 1808, 19th St., Parkersburg, W. Va.

CUTBILL, HERBERT WILLIAM, Engineering Dept., New York Edison Co., 130 E. 15th St., New York; res., Yonkers, N. Y.

*DAVIS, GEORGE G., Electrical Draftsman, Philadelphia Electric Co., 23rd & Market Sts., Philadelphia, Pa.; res., Camden, N. J.

DAY, CHARLES CURTIS, Load Dispatcher, Consumers Power Co., 224-44 W. Main St., Jackson, Mich.

DEDERMAN, RUDOLPH H., Engineering Dept., Toledo Edison Co., Toledo, Ohio.

del VECCHIO, E. JULIAN, Power Plant Engineer, Pejepscot Paper Co., Pejepscot Mills; res., Brunswick, Me

DEY, ANTHONY ROBERT, Electrician, Pennsylvania Water & Power Co., 2940 E. Fayette St., Baltimore, Md.

DIKE, PERCY R., Head Draftsman, Commonwealth Edison Co., 72 W. Adams St., Chicago, Ill.

*DONALDSON, CHASE, Investigator, Hayden, Stone & Co., 25 Broad St., New York; res., Great Neck, L. I., N. Y.

*DONAHOE, ROBERT E., Student, University of Minnesota, Minneapolis, Minn.

*DORAN, JOHN E., Engineer, Dist. Dept., United Gas & Electric Co., 224 W. 8th St., Cincinnati, Ohio.

DORNEMAN, WILLIAM CLAYTON, System Operator, Pennsylvania Power & Light Co., Hazleton, Pa.

DOW, MORRILL THORNTON, Instructor, Electrical Engineering Dept., Mass., Institute of Technology, Cambridge, Mass.

DOYLE, JOHN F., Foreman, Electrical Construction, Brooklyn Edison Company, 95 Jay St., Brooklyn, N. Y.

DRIVER, WILFRED H., Supt., Macan Jr. Co., Easton; res., Brooklyn, Pa.

*DRUM, GEORGE FREDERICK, Engineering Dept., American Tel. & Tel. Co., 195 Broadway, New York, N. Y.

*DUDLEY, CARLTON LEWIS, Cadet Engineer, Public Service Electric Co., 80 Park Place, Newark; res., Arlington, N. J.

DUNCAN, PETER ALEXANDER, Student Engineer, General Electric Co., Schenectady, N. Y.

EINSTEIN, MAJOR B., Standard Underground Cable Company, 4121 N. Kingshighway Blvd., St. Louis, Mo.

ELLIOTT, ROBERT CARROLL, Meter Foreman, Washington Coast Utilities, Wenatchee, Wash.

ENGSBURG, RALPH W., Equipment Engineer, Automatic Electric Co., 927 W. Van Buren St., Chicago; res., Oak Park, Ill.

ENOCHS, ARVEL RAY, Construction Engineer, West Virginia Engineering Co., Charleston, W. Va.

FARRAR, CLYDE LEO, Instructor in Charge of Practical Electricity for Vocational Training, State College of A. & M. Arts, Las Curces, New Mexico.

*FAUCETT, MAX ALBERT, Assistant in Electrical Engineering, University of Illinois Urbana, Ill.

FITZGERALD, THOMAS CONOLLY, Student, University of Illinois, Urbana; Station A, Champaign, Ill.

FLETCHER, THOMAS LEE, Substation Operator, Potomac Electric Power Co., 14th & C. Sts., N. W., Washington, D. C.

*FLINT, ERLON WEBSTER, Test Engineer, Western Electric Co., 463 West St., New York, N. Y.

*FORD, C. R., Construction Foreman, General Electric Company, Atlanta, Ga.

FREIBERG, LOUIS, Inspector of Light & Power, Dept. of Water Supply, Gas & Electricity, Municipal Bldg., New York, N.Y.

*FRIEDMAN, BERNARD D., Asst. Foreman, The Cleveland Leader News Company, Cleveland, Ohio.

FRIERMUTH, OTTO, Designing Engineering Dept., Brooklyn Edison Co., Sperry Bldg., Brooklyn, N. Y.

GARVIN, JOHN P., Hydro-Power Plant Operator, Great Northern Railway, Leavenworth, Wash.

GEORGESON, JAMES, Electrical Draftsman, Pacific Gas & Electric Co., 445 Sutter St., San Francisco, Calif.

GILBERT, JOSEPH LLOYD, Testing Dept., Westinghouse Electric & Mfg. Co., E. Pittsburgh; res., Wilkinsburg, Pa.

GILCHRIST, LAURENCE FOLEY, Assistant Foreman, Meter & Test Dept., B. F. Goodrich Co., Akron; res., Kenmore, Ohio.

GILL, GEORGE JAMES, Electrical Draftsman, Potomac Electric Power Co., Washington, D. C.

GILROY, WILLIAM J., Electrician, Ryan & Dipple, Shell Road & Neptune Ave., Coney Island, N. Y.

GLIDDEN, CARL M Sales Engineer, Northern States Power Co., 15 So. 5th St., Minneapolis, Minn.

GOLDENBERG, FRANK, Electrical Engineering Dept., Pennsylvania Water & Power Co., 1611 Lexington Bldg., Baltimore, Md.

*GRAF, FRANK GEORGE, Estimating Engineer, Western Electric Co., 397-401 Hudson St., New York; res., Richmond Hill, N. Y.

*GRAFF, MILTON WERNER, Engineer, City of Norwich Gas & Electric Dept., 37 Shetucket St., Norwich, Conn.

GRAFFIUS, JOHN L., Assistant Engineer, Duquesne Light Co., 501 Chamber of Commerce Bldg., Pittsburgh, Pa.

GRANT, CLARENCE T., Electrical Engineer, Western Electric Co., 463 West St., New York, N. Y.

HABRYL, LOUIS LEROY, Lieut., U. S. Navy, U. S. S. R-9; for mail, Postmaster, New York, N. Y.

HAINES, THOMAS HENRY, Asst. Supt., Maintenance Lines Dept., Edison Elec. Ill. Co. of Boston, 1165 Mass. Ave., Boston, Mass.

HALLEY, GEORGE R., Load Dispatcher, Consumers Power Co., Jackson, Mich.

HAMER, WILLIAM H., Assistant Engineer, Electric Bond & Share Co., 71 Broadway, New York, N. Y.

HANSEN, OVE R., Power Maintenance, Michigan State Telephone Co., 1365 Cass Ave., Detroit, Mich.

*HANTZSCH, RALPH E., Engineering Dept., Western Electric Co., 463 West St., New York; res., Rockville Center, N. Y.

HARPER, WILLIAM WIRICK, Radio Inspector, U. S. Navy Dept., Great Lakes; res., Chicago, Ill.

HARRIS, CLARENCE W., Jr., Automotive Electrical Work, Michael Ert., Inc., 530 Jefferson St., Milwaukee, Wis.

HARRIS, HIRAM ELMER, Asst. Engineer, Instrument Transformer Dept., General Electric Co., W. Lynn; res., Swampscott, Mass.

*HARTMAN, JOHN RUSSELL, Switchboard Sales Dept., General Electric Co., Schenectady, N. Y.

*HARVEY, FRED T., Flowmeter Specialist, General Electric Co., 120 Broadway, New York, N. Y.

HARVEY, HADLEY, Sales Engineer, Gellatly & Co., 2205 Oliver Bldg., Pittsburgh; res., Johnstown, Pa.

HASENAUER, ELMER GEORGE, Sales Engineer, Century Electric Co., 632 Granite Bldg., Rochester, N. Y.

*HEACOCK, WARD JAMES, Industrial Control Engineer, General Electric Co., Schenectady, N. Y.

HEART, HERBERT LOEB, Electrical Engineer, Otis Elevator Co., 260 11th Ave., New York, N. Y.

HEATH, EDMUND F., Inspector, Electrical Engineer's Dept., Brooklyn Edison Co., 360 Pearl St., Brooklyn, N. Y.

*HECKER, WALTER JACOB, Student, Electrical Engineering Dept., Marquette University, Milwaukee, Wis.

HELLER, ROBERT W., Control Engineering Dept., Westinghouse Elec. & Mfg. Co., E. Pittsburgh; res., Wilkinsburg, Pa.

HENDERSON, MORROW C., Assistant Field Engineer, Duquesne Light Co., 435 6th Ave., Pittsburgh; res., Crafton, Pa.

HENDRICKS, JOHN ANDREW, Load Dispatcher, West Penn Power Co., 14 Wood St., Pittsburgh, Pa.

HENDRICKSON, FREDERICK, Estimator, Western Electric Co., 397 Hudson St., New York, N. Y.

*HENNEBERGER, THOMAS CLINTON, Telephone Engineer, American Tel. & Tel. Co., 195 Broadway, New York, N. Y.

*HICKS, ROBERT C., Jr., Asst. Electrical Designer, The Philadelphia Electric Co., 1000 Chestnut St., Philadelphia, Pa.

HIRAGI, MINEO, Graduate Student of Elec. Engineering, Cornell University, Ithaca, N. Y.

HODGKIN, JOHN D., Operator, Potomac Electric Power Co., Washington, D. C.; res., Ammendale Md.

HOENACK, OTTO, Instrument Maker, Paul Hoenack, 108 Park Row, New York, N. Y.

*HOERNEL, PAUL CHRISTOPHER, Instructor of Physics, Brooklyn Polytechnic Institute, 85 Livingston St., Brooklyn; res., Babylon, N. Y.

*HOFFMEYER, HERMAN F. L., Jr., Southern Railway Company, 1430 Cherokee St, Columbia, S. C.

*HOLLAND, NORMAN NORWOOD, Technical Assistant, to George Ramsey, 4705 Woolworth Bldg., New York, N. Y.

HOLLINGSHEAD, PAUL HENRY, Electrical Draughtsman, Starrett & Van Vleck, 8 W. 40th St., New York, N. Y.

HORIOKA, MASAIE, Electrical Engineer, Electro-technical Laboratory, Dept. of Communication, Tokyo, Japan.

*HOWARTH, JOHN MONROE, Assistant Engineer, Adirondack Power & Light Corp., 511 State St., Schenectady, N. Y.

*HOWES, DOUGLAS EDWARD, Research Engineer, Research Laboratory, Westinghouse Electric & Mfg. Co., E. Pittsburgh, Pa.

*HUDSON, CARROLL DELMAR, Electrical Engineering Dept., Llewellyn Iron Works, 1200 No. Main St., Los Angeles, Calif.

*INGRAHAM, DWIGHT MARDEN, Assistant, Engineering Dept., Bell Telephone Company of Pa., 216 N. Broad St., Philadelphia, Pa.

JABLONSKI, HENRY A., Inspector, Western Electric Co., 61 Irving Place, New York, N. Y.; res., Bayonne, N. J.

*JACKSON, DUGALD CALEB, Jr., Instructor Dept. of Electrical Engineering, University of Missouri, Columbia, Mo.

JAMES, GEORGE IRVING, Supt. of Construction, Stone & Webster, 147 Milk St., Boston, Mass.

*JANES, LEONARD REED, Research Assistant, Mass. Institute of Technology, Cambridge, Mass.

*JENNINGS, FRANK BROWN, Equipment Engineer, New York Telephone Company, 81 Willoughby St., Brooklyn, N. Y.

JOHNSON, ANDERS VICTOR, Electrical Tester, General Electric Co., River Works, W. Lynn; res., Malden, Mass.

*JOHNSON, ELMER DEWEY, Instructor, Electrical Engineering Dept., University of Pittsburgh, Pittsburgh; res., Wilkinsburg, Pa.

JOHNSON, IVAN T., President, Ivan T. Johnson Company, Inc., 24 E. 23rd St., New York, N. Y.

JOHNSON, OLAN C., Methods & Investigation Division, Western Electric Co., Hawthorne; res., Chicago, Ill.

JOHNSON, UNO, High Tension Operator, Central Station, Flatbush Gas Co., 321 Clarkson Ave., Brooklyn, N. Y.

JONES, ERLE MILLER, Sales Manager, W. H. Banfield & Sons, Ltd., 370 Pape Ave., Toronto, Ont., Can.

*JONES, JOHN COLEMAN, Asst., Electrical Engineering Dept., Mass. Institute of Technology, Cambridge, Mass.

*JONES, WILLIAM BLAIR, Distribution Engineering Dept., West Penn Power Co., 14 Wood St., Pittsburgh, Pa.

KANE, EDWARD W., Instructor in Electrical Engineering, Marquette University, 1115 Grand Ave., Milwaukee, Wis.

KEEBLER, HOWARD MARSHALL, Division Chief, Laboratory, Philadelphia Electric Co., 2301 Market St., Philadelphia; res., Norwood, Pa.

KEITH, ALFRED SHELTON, Asst. to Vice-President, West Penn Power Co., 14 Wood St., Pittsburgh, Pa.

KENDALL, ALLEN B., Signal Engineer, The Regan Safety Devices Co., Inc., U. S. Light & Heat Corp., Niagara Falls, N. Y.

KLINE, ELMER E., Foreman, Electric Meter Dept., Union Gas & Electric Co., 4th & Plum, Cincinnati, Ohio.

*KLIPPEL, EARL FREDERICK, Student, Lehigh University, 461 Montclair Ave., Bethlehem, Pa.

*KNAELL, K. K., Plant Engineer, Macbeth-Evans Glass Co., Charleroi, Pa.

*KNOERR, RUDOLPH R., Asst. Designing Engineer, General Electric Co., Lynn, Mass.

*KNOX, RAYMOND SCOTT, Cadet Engineer, Consolidated Gas Company of New Jersey, 176 Broadway, Long Branch, N. J.

*KRATZER, JOSEPH B., Interstate Electric Company of New Orleans, Perdido & Barone Sts., New Orleans, La.; Meridian, Miss.

LAING, STERLING DEAN, Line Foreman, Kansas Gas & Electric Company, Moline, Kansas.

LAJOIE, GEORGE A. L., Electrical Engineer, Southern Canada Power Co., 330 Coristine Bldg., Montreal, Que.

LAKE, MARSHALL EDGAR, Asst. Engineer, Mill Power Dept., Southern Power Co., Charlotte, N. C.

*LAMBERT, KENNETH BENNETT, Engineering Dept., Western Electric Co., Inc., 463 West St., New York, N. Y.; res., Glen Ridge, N. J.

LAROM, AUGUSTUS P., Inspector, Western Electric Co., 61 Irving Place, New York; res., Brooklyn, N. Y.

*LARSON, LUDVIG CONRAD, Teaching Fellow, University of Minnesota, Minneapolis, Minn.

*LAWRENCE, EUGENE C., Electrical Engineer, Edison Lamp Works of General Electric Co., Harrison; res., Bellville, N. J.

*LEMEN, FOSTER MILO, Manager, Lemen Electric Company, Delta, Iowa.

*LEVY, BENJAMIN, Engineering Dept., Public Service Electric Co., 102 River St., Newark, N. J.

*LEWELLING, RAYMOND, Junior Electrical Engineer, Bureau of Power & Light, 207 South Broadway, Los Angeles, Calif.

LEWIS, THOMAS P., Asst. to Supt., Underground Cable Work, Commonwealth Edison Co., 72 W. Adams St., Chicago, Ill.

*LITTLE, H. BOYD, Executive Dept., Toronto Hydro-Electric System, Yonge St., Toronto, Ont.

LITTMAN, LAWRENCE, Efficiency Engineer, U. S. Cast Iron Pipe & Foundry Co., Bessemer, Ala.

LUMLEY, CHARLES SWAIN, Electrical Draftsman, New York Edison Co., 130 E. 15th St., New York, N. Y.; res., Newark, N. J.

*MAGANN, JOSEPH WILBUR, Graduate Student & Research Engineer in Physics, University of Wisconsin, Sterling Hall, Madison, Wis.

MALLORY, FRANK DRAKE, Jr., Lighting Specialist, Dallas Power & Light Co., Dallas Texas.

*MANEY, WALLACE LINCOLN, Testing Dept., General Electric Company, Schenectady, N. Y.

*MANNING, ALLEN MONROE, Construction Foreman, Portland Railway, Light & Power Co., Portland; res., Vancouver, Ore.

MARBURY, RALPH EUGENE, Supply Engineering Dept., Westinghouse Electric & Mfg. Co., E. Pittsburgh, Pa.

*McCARTY, ROBERT SKILES, Assistant Engineer, Duquesne Light Co., 501 Chamber of Commerce Bldg., Pittsburgh; res., Wilkinsburg, Pa.

McCONNELL, PRICE, Foreman of Substations, Anaconda Copper Mining Co., Anaconda, Mont.

McDONALD, CYRIL G. H., Railway Engineering Dept. General Electric Co., Schenectady, N. Y.

*McMILLEN, JAMES S., Sales Dept., Minneapolis General Electric Co., 15 S. 5th St., St. Paul, Minn.

McPHERSON, WILLIAM BUTLER, Electrician, Minnesota By-Product Coke Co., 1000 Hambine Ave., St. Paul, Minn.

*MERCER, WILLIAM HARRY, Engineering Assistant, The Delaware & Atlantic Tel. & Tel. Co., 521 Federal St., Camden; res., Collingswood, N. J.

MELVILLE, SAMUEL PETER, Electrical Engineer, Stone & Webster, Inc., 147 Milk St., Boston, Mass.

*MERRIMAN, ARTHUR GATES, Instructor, Electrical Engineering Dept., Purdue University, W. Lafayette, Ind.

*MISZKIEL, VICTOR S., Cadet Engineer, Phoenix Utility Co., 22 Carey St., Ashley, Pa.

*MITCHELL, CHESTER FLOYD, Distribution Division, Commonwealth Edison Co., 72 W. Adams St., Chicago, Ill.

*MOCKRIDGE, CHARLES COX, 380 W. Blackwell St., Dover, N. J.

MOESEL, ERNEST, Electrical Draftsman, Western Electric Co., 463 West St., New York, N. Y.

*MOESLEIN, EDWARD D. W., Plant Engineer, New York Telephone Company, 227 E. 30th St., New York, N. Y.

MOESTA, FREDERICK EDWARD, Plant Engineer, The Ohio Bell Telephone Co., 4300 Euclid Ave., Cleveland, res., Lakewood, Ohio.

MONAHAN, HARRY WILLIAM, Manager, Electric Sales Engineering Co., 228 S. May St., Ft. William, Ont., Can.

MONTAGUE, BENJAMIN FRANKLIN, Engineer, The Virginian Power Co., Charleston, W. Va.

MORRIS, ADOLPH FRANKFORT, Central Station Operator, Potomac Electric Power Co., Bennings, D. C.; res., Bethesda, Md.

MORSS, CHARLES ANTHONY, JR., Simplex Wire & Cable Co., 63 Sidney St., Cambridge, Mass.

MUKHERJIE, U. N., Electrical Supervisor, Indian Telegraphs, Government Telegraph Office, Patna, India.

*NAKAMURA, JISUKE, Tester, Westinghouse Electric & Mfg. Co., E. Pittsburgh; res., Wilkinsburg, Pa.

*NEVINS, Ben R., Assistant Inspector, Station Construction, Philadelphia Electric Co., 1000 Chestnut St., Philadelphia, Pa.

NIGOSIAN, NIGOGHOS AVEDIS, Electrical Engineering Division, Goodyear Tire & Rubber Co., Akron, Ohio.

NISBET, CARRICK, Battery Service Station & Repairs, Hood Street, Hamilton, New Zealand.

NOVAK, JOE J., Publisher, "Radio Topics," 1112 North Boulevard, Oak Park; res., Chicago, Ill.

OLIVER, J. GUY, Engineering & Construction Dept., Carolina Power & Light Co., Raleigh, N. C.

OLMEDO, HECTOR HERMANDEZ, Allis-Chalmers Mfg. Co., Milwaukee, Wis

*OTTEN, HARRY CHARLES, Engineering Assistant, United Electric Light & Power Co., 130 E. 15th St., New York; res., Brooklyn, N. Y.

OTTING, BERNARD, Chief Electrician, The Cincinnati Ball Crank Co., North St., Oakley, Cincinnati, Ohio.

OUTHWAITE, FRANK H., Electrical Draftsman, McClellan & Junkersfeld, Inc., 45 William St., New York, N. Y.

*OVERSTREET, FRANK A., Operator, Utah Power & Light Company, Grace, Idaho.

PARKER, EDWARD MARTIN, Electrical Inspector, Westchester Lighting Company, Mt. Vernon, N. Y.

PEASE, HAROLD CHESTER, Municipal Light Plant, E. 53rd & Lake Front, Cleveland, Ohio.

PEOPLES, ROBERT E., Telephone Engineer, Western Electric Co., Inc., 463 West St., New York, N. Y.

PERRY, CHARLES HOWARD, Sales Dept., Central Station Division, Westinghouse Elec. & Mfg. Co., 3rd. & Elm Sts., Cincinnati, Ohio.

PFROMM, CONRAD WILBUR, Electrical Draftsman, Pennsylvania Power & Light Co., Hazleton, Pa.

PILLAY, PADMANABHA S., Chief Engineer, The Tata Oil Mills, Ltd., Cochin, South India.

PIRTLE, JAMES LUTHER, Designer, McClellan & Junkersfeld, 45 William St., New York; res., Brooklyn, N. Y.

POHJA, HAROLD WAYNE, Duquesne Light Co., 435 Sixth Ave., Pittsburgh, Pa.

*POLAND, FRANK FREDERICK, Engineering Dept., Baltimore Copper Smelting & Rolling Co., Baltimore, Md.

PORTER, GEORGE McCANDLESS, Asst. Professor of Electrical Engineering, Carnegie Institute of Technology, Pittsburgh, Pa.

*POWELL, GEORGE ALFRED, Load Dispatcher, Adirondack Power & Light Corp., 2518 Broadway, Watervliet; res., Schenectady, N. Y.

POWELL, WILLIAM HUNTER, Sales Engineer, Bristol Company, Waterbury, Conn.

*PRESTON, JACK DEGGE, Asst. Instructor, Mass. Institute of Technology, Cambridge, Mass.

PRITCHARD, CLARENCE WATSON, Electrical Machinist, Potomac Electric Power Co., 17 14th St., S. E., Washington, D. C.

RAYMOND, CHARLES S., Electrical Engineer, General Electric Co., Schenectady, N. Y.

*RAYNER, REID L., Graduate Asst., Electrical Engineering Dept., Michigan Agricultural College, E. Lansing, Mich.

REDFERN, HAZEN G., District Foreman, Electrical Dept., San Joaquin Light & Power Corp., Dinuba, Calif.

REED, LINWOOD E., Electrical Draftsman, Potomac Electric Power Co., Washington, D. C.

REYNOLDS, FOSTER RAY, Salesman, Westinghouse, Electric & Mfg. Co., Miners Bank Bldg., Wilkes-Barre; res., Kingston, Pa.

RICKERD, CECIL W., A-B-C Refrigerating System, N. Y. Steam Bldg., 40th St. & Madison Ave., New York; res., Peekskill, N. Y.

ROBERTSON JOHN, Managing Director, John Robertson (B) Ltd., 79 May St., Belfast, Ireland.

ROBERTSON, WILLIAM E. G., Salesman, Toronto Hydro-Electric System, 225 Yonge St. Toronto, Ont., Canada.

ROBINS, ORRIN ASBURY, Secretary, The Electric League, 243 N. High St., Columbus, Ohio.

*ROEHRIG, FREDERICK AUSTIN, Small Motor Specialist, Westinghouse Elec. & Mfg. Co., Union Bank Bldg., Pittsburgh; res., Wilkinsburg, Pa.

ROGERS, WARREN ALFRED, Electrician, V. Philipsen, 575 4th Ave., Brooklyn, N. Y.

*ROITBURD, JACK R., Wireman, Public Service Production Co., 15 Park Place, Newark, N. J.; res., New York, N. Y.

*ROSEBRUGH, DAVID WELLESLEY, Canadian General Electric Co., Peterborough; res., Toronto, Ont., Canada.

*ROSENBACH, SAMUEL, Junior Engineer, Duquesne Light Company, 501 Chamber of Commerce Bldg., Pittsburgh, Pa.

ROSS, BYRON ARCHER, Electrical Construction Foreman, Phoenix Utility Co., Hazleton, Pa.

*SALTER, ERNEST HIRES, Instructor, Electrical Engineering Dept., Purdue University, Lafayette, Ind.

*SANBORN, EDGAR F., Seaboard Air Line Railway, Portsmouth, Va.

SANDERSON, GEORGE EDWIN, Sales Dept., Eck Dynamo & Motor Co., Mill & Main Sts., Belleville; res., Newark, N. J.

SANFORD, WILLIAM JAMES, General Manager, Nuevitas Div., Camaguey Electric Co., Camaguey, Cuba.

SCHAUER, WILLIAM, General Utility Dept., General Electric Co., 1309 Oliver Bldg., Pittsburgh, Pa.

*SCHIPPEL, WALTER HERBERT, Demonstrator, Electrical Dept., McGill University, Montreal; res., Outremont, Que.

*SCHRAGE, CHARLES THAYER, Technical Employee, American Tel. & Tel. Co., 311 W. Washington St., Chicago, Ill.

*SCHRAMM, FRED W., Instructor, Electrical Engineering Dept., Washington University, St. Louis, Mo.

SCHUMACHER, HARRY E., Inspector, 13-21 Park Row, New York; res., Brooklyn, N. Y.

SEDDON, RICHARD I., Electrical Engineer, The Penitentiary Commission, New Illinois State Penitentiary, Lockport; res., Joliet, Ill.

SEIDMAN, LOUIS B., Student, Fordham University, New York; res., Brooklyn, N. Y.

SESSIONS, ROBERT CRIGHTON, Engineer, Frank L. Sessions, 422 Kirby Bldg., Cleveland, O.

SHANAHAN, OLIVER J., Asst. to Supt., Substation Construction, West Penn Power Co., 14 Wood St., Pittsburgh, Pa.

SHUTTS, WALTER LOUIS, Meter Inspector, Duquesne Light Co., 3708 5th Ave., Pittsburgh; res., Erie, Pa.

SILLDORFF, HENRY C., Sales Engineer, Weston Electrical Instrument Co., Waverly Park, Newark; res., Nutley, N. J.

SINEX, REUBEN THOMAS, Chief Draftsman, Puget Sound Power & Light Co., 605 Electric Bldg., Seattle, Wash.

SMITH, ARTHUR BLISS, Reorganizing City, Light & Power Distribution, St. Johns Light & Power Co., St. Johns, Newfoundland.

*SMITH, AUBREY MILLER, Electrical Engineer, General Electric Co., Schenectady, N. Y.

SMITH, BERNARD, Instructor, Electrical Engineering Dept., University of Arkansas, Fayetteville, Ark.

SMITH, FRANK VERNON, General Engineer, Westinghouse Electric & Mfg. Co., E. Pittsburgh; res., Wilkinsburg, Pa.

*SMITH, FREDERICK JOHN, Laboratory Assistant, Hydro-Electric Power Commission of Ontario, 8 Strachan Ave., Toronto, Ont.

SMITH, RUSSELL HAWLEY, Asst. Engineer, United Electric Light & Power Co., 130 E. 15th St., New York, N. Y.; res., 182 White St., Stratford, Conn.

*SMITH, WALTER F., JR., Engineering Dept., Western Electric Co., 463 West St., New York, N. Y.

SMITH, WILBERT HENRY, Electrical Draftsman, McClellan & Junkersfeld, 45 William St., New York, N. Y.

*SNIDER, WILLIAM HERBERT, Asst. Electrical Engineer, United Light & Railway Co.; res., 5 Walling Court, Davenport, Ia.

SONKIN, DAVID, Radio Engineer, 347 Hudson St., New York, N. Y.

*SPOONER, HOWARD MARSHALL, Public Service Production Co., 80 Park Place, Newark; res., Rahway, N. J.

SPRACKLEN, EMERY EVELIEGH, Electrical Designer, The Ohio Public Service Co., Peoples Bank Bldg., Alliance, Ohio.

SPRAKER, JOSEPH GARLAND, Substation Operator, Potomac Electric Power Co., Sherman Ave. & Harvard St., N. W., Washington, D. C.; res., McLean, Va.

SPURLING, WALTER EVERARD, Asst. Manager, Bermuda Elec. Light, Power & Traction Co., Ltd., Serpentine Road, Pembroke Parish, Bermuda Islands.

STANGER, EDWARD ARTHUR, Distribution Engineer, Southern Canada Power Co., Ltd., 330 Coristine Bldg., Montreal, Que.

STEINBERG, JOHN CHRIS, Research Engineer, Western Electric Co., 463 West St., New York, N. Y.

STEWART, MALCOLM GORDON, Southern Canada Power Company, 20 St. Nicholal Bldg., Montreal, Que.

STROMBERG, PETTER JOHAN, Electrical Engineer, Canadian General Electric Co., 212 King St. W., Toronto; res., Niagara Falls, Ont., Canada.

SUN, KUO-FENG, Electrical Tester, Standardizing Laboratory, General Electric Co., W. Lynn, Mass.

*THAKKUR, KHIMJI BHANJI, Graduate Student, Mass. Institute of Technology, Cambridge, Mass.

THOMAS, CHARLES ANDREW, Substation Operator, Potomac Electric Power Co., 14th & C. St., N. W., Washington, D. C.

THOMPSON, ALBERT VAIL, Asst. Local Sales Manager, General Electric Co., San Francisco, Calif.

*THOMPSON, FRANCIS RAYMOND, Graduate Engineering Apprentice, Westinghouse Electric & Mfg. Co., E. Pittsburgh; res., Pittsburgh, Pa.

*THOR, BERG V., Electrical Tester, Westinghouse Electric & Mfg. Co., E. Pittsburgh; res., Turtle Creek, Pa.

TOWNSEND, HENRY W., Electrical Foreman, A. T. & S. F. R. R. Co., Argentine, Kans.; res., Kansas City, Mo.

*TREVETT, HAROLD NEWTON, Instructor, Rensselaer Polytechnic Institute, 96 Eagle St., Troy, N. Y.

TUBBS, LESTER G., Motor Engineering Dept., Westinghouse Electric & Mfg. Co., E. Pittsburgh; res., Wilkinsburg, Pa.

TUGENDHAT, G. ROBERT, Inventor, 124 W. 82nd St., New York, N. Y.

TUSKA, CLARENCE DENTON, President, C. D. Tuska Company, 69 Bartholomew Ave., Hartford, Conn.

URBAN, STEPHEN, Jr., Armature Winder, Perth Amboy Electric Co., 260 Madison Ave., Perth Amboy; res., Avenel, N. J.

*VAN ARK, James F., Telephone Engineer, Western Electric Company, Chicago; res., Downers Grove, Ill.

VAN ARSDEL, ERNEST, Vice-President in charge of Operation, Interstate Public Service Co., 510 Board of Trade, Indianapolis, Ind.

VANDER, WILLIAM C., Instructor, Technical High School, Fall River; res., New Bedford, Mass.

VAN GORDER, COURTLAND THOMAS, Student, Engineering School of Milwaukee, 415 Marshall St., Milwaukee, Wis.

VAN NESS, BARTOW, Jr., Tester, Pennsylvania Water & Power Co., 1611 Lexington Bldg., Baltimore, Md.

VENTURINE, JULIAN B., Chief Electrical Engineer, Clark & Wilson Lumber Co., Linnton, Ore.

VOGEL, DAVID, Draftsman, Dept. of Water Supply, Gas & Electricity, Municipal Bldg., New York; res., Brooklyn, N. Y.

VORHES, HAROLD ROGER, Foreman, Switchboard Dept., Westinghouse Electric & Mfg. Co., 1400 4th St., San Francisco, Calif.

WALD, ALBERT, Treasurer & Sales Manager, Wald Electric Mfg. Corp., 248-256 N. 10th St., Brooklyn; res., New York, N. Y.

WALSH, THOMAS HENRY, Electrical Engineer, J. A. P. Crisfield Contracting Co., Devon, Conn.

WALTER, GILBERT PROWELL, Central Station Operator, Potomac Electric Power Co., Washington, D. C.

WARREN, CLAUDE AUGUSTA, Station Wireman, Portland Railway, Light & Power Co., Hawthorne Bldg., Portland, Ore.

*WATKINS, WILLIS W., Switchboard Engineer, Westinghouse Electric & Mfg. Co., E. Pittsburgh; res., Wilkinsburg, Pa.

*WAY, HOWARD ELMORE, Special Agent, Electrical Division, Bureau of Foreign & Domestic Commerce, 1916 I St., N. W., Washington, D. C.

WEBB, JOHN K., Foreman of Construction, Cleveland Electric Illuminating Co., East Cleveland, Ohio.

*WEBB, WILLIAM L., Testing Dept., General Electric Co., Schenectady, N. Y.

*WEIGEL, FREDERICK ALBERT, Transformer Engineering Dept., General Electric Co., W. Lynn; res., Lynn, Mass.

*WEIKEL, WILLIAM STEWART, Testing Dept., General Electric Co., Schenectady, N. Y.

WEISS, W. ROBINSON, Asst. Results Engineer, The Denver Gas & Electric Light Co., Lacombe Station, Denver, Colo

WEST, CHARLES REED, Electrical Draftsman, Philadelphia Rapid Transit Co., 820 Dauphin St., Philadelphia, Pa.

WESTERLUND, GEORGE EDMUND, Electrician, Charles J. Woodward, Jr., 4506, 3rd Ave., Brooklyn, N. Y.

WETSTEN, RALPH STANLEY, Cadet Engineer, Public Service Electric Co., 80 Park Place, Newark, N. J.

*WHELEN, MORLAND POWERS, Jr. Engineer, Power Sales Dept., Toronto Hydro-Electric System, Ryrie Bldg., Toronto, Ont., Can.

*WHITFORD, RALPH ALONZO, Student Engineer, General Electric Co., 5 Frank St., Schenectady, N. Y.

WHITMORE, HAROLD B., Assistant Examiner, U. S. Patent Office, Washington, D. C.

WILLIAMS, DAVID, Squad Leader, Engineering Dept., New York Edison Co., 130 E. 15th St., New York, N. Y.

WILLOUGHBY, THOMAS SMITH, Mechanical Draftsman, George P. Carver, Inc., 261 Franklin St., Boston; res., Medford, Mass.

WILSON, ARTHUR STANLEY, Assistant, Line Maintenance Dept., Hydro-Electric Power Commission, 43 Hughson St. N., Hamilton, Ont., Can.

WILSON, ELMER J., Asst. to Manager, River Works, General Electric Co., W. Lynn, Mass.

WILSON, J. M., Supt., Virginia Western Power Co., Hinton, W. Va.

WINCKLER, GEORGE A., Electrical Cable Engineering, American Steel & Wire Co., Worcester, Mass.

*WINTERHALTER, T. S., Engineering Assistant, Public Service Production Co., 15 E. Park St., Newark; res., Bayonne, N. J.

*WOELLERT, LESTER N., Student, School of Engineering of Milwaukee, Milwaukee, Wis.

WOLF, SIDNEY K., Electrical Heating Engineering Dept., Westinghouse Elec. & Mfg. Co., E. Pittsburgh; 4902 Forbes St., Pittsburgh, Pa.

*WOOD, CARL E., Special Apprentice, Mechanical Dept., Chicago, Milwaukee & St. Paul Railway, Deer Lodge, Mont.

WOODZELLE, GUY WILLIAM, 5460 Penn Ave., Pittsburgh, Pa.

WORCESTER, DEAN KIRKHAM, Student Engineer, New York Telephone Co., 104 Broad St., New York, N. Y.

WRIGLEY, ALBERT E., Resident Electrician, Thames Valley Power Board, Matamata, Rotuta Line, N. Z.

YARVOTS, EVART, Storage Battery Inspector, Exide Battery Co., 101 West End Ave., New York, N. Y.; res., Jersey City, N. J.

YOUNG, HENRY PERCY, Lecturer in Electrical Engineering, The Polytechnic, Regent St., London W. 1, England.

*YOUNGSTROM, NELS CLINTON, Engineer, Cost Dept., Hannawa Falls Water Power Co., Potsdam, N. Y.

ZIMMERMANN, JAMES EDWARD, Equipment Engineer, Wisconsin Telephone Co., 418 Broadway, Milwaukee, Wis.

Total 326.

*Formerly Enrolled Students.

ASSOCIATES REELECTED JANUARY 17, 1923

FRAILEY, CHARLES N., Engineer-Salesman, 717 S. 12th St., St. Louis, Mo.

MANSON, ARTHUR J., Manager, Transportation Division, Westinghouse Electric & Mfg. Co., 165 Broadway, New York N. Y.

NORTON, FAY ARTHUR, Asst. Professor of Coordination, University of Cincinnati, Cincinnati, Ohio.

OWEN, WILLIAM B., Electrical Engineer, Pennsylvania Power & Light Co., Wilkes-Barre, Pa.; Electric Bond & Share Co., 71 Broadway, New York, N. Y.

FELLOW REELECTED JANUARY 17, 1923

JOHANNESEN, SVEND EMANUEL, Transforming Engineering Dept., General Electric Co., Pittsfield, Mass.

MEMBERS ELECTED JANUARY 17, 1923

BULL, EDWIN A., General Manager, Produce Terminal Corp., Union Stock Yards, 3 Dexter Park Ave., Chicago, Ill.

CUDEBEC, ALBERT B., Consulting Engineer, 3 rue Taitbout, Paris, France.

KIETZMAN, WILLIAM ARTHUR, General Commercial Engineer, Bell Telephone Company of Pa., 261 N. Broad St., Philadelphia, Pa.

SUMPTER, JOHN E., Owner, J. E. Sumpter Co., 222 Security Bldg., Minneapolis, Minn.

WASHINGTON, BOWDEN, Chief Engineer, Independent Wireless Telegraph Co., Inc., 35 Water St., New York; res., Woodmere, N. Y.

TRANSFERRED TO GRADE OF FELLOW, JANUARY 17, 1923

RYAN, HARRIS J., Professor of Electrical Engineering, Stanford University, Stanford University, Calif.

TRANSFERRED TO GRADE OF MEMBER, JANUARY 17, 1923

DYSTERUD, EMIL, Manager, Light & Power Dept., Monterey Railway, Light & Power Co., Monterey, N. L., Mexico.

FOSTER, EDWARD S., Assistant Chief Engineer, Packard Electric Co., Warren, Ohio.

ISDALE, JOHN S., Electrical Superintendent, New York Harbor Drydock Corp., Rosebank, S. I., N. Y.

KIRKWOOD, MACLEAN, Telegraph Engineering, American Telephone & Telegraph Co., New York, N. Y.

MOORE, WILLIAM A., Electrical Engineer, Hugh L. Thompson, Waterbury, Conn.

OEHLER, ALFRED G., Editor, *Railway Electrical Engineer*, New York, N. Y.

WOODWARD, DANIEL H., Division Plant Engineer, American Telephone & Telegraph Co., Atlanta, Ga.

RECOMMENDED FOR TRANSFER

The Board of Examiners, at its meeting held January 15, 1923, recommended the following members of the Institute for transfer to the grades of membership indicated. Any objection to these transfers should be filed at once with the Secretary.

To Grade of Fellow

MILLS, JOHN, Assistant Personnel Manager, Western Electric Co., New York, N. Y.

PECK, EMERSON P., General Supt., Electrical Dept., Utica Gas & Electric Co., Utica, N. Y.

THURSTON, ERNEST B., Chief Electrical Engineer, Haughton Elevator & Machine Co., Toledo, O.

TRACY, ATLEE H., Electrical Engineer, Byllesby Engineering & Management Corp., Chicago, Ill.

To Grade of Member

BASSETT, JOHN B., Assistant District Engineer General Electric Co., New York, N. Y.

BEERS, HAROLD S., Electrical Superintendent, Tallassee Power Co., Badin, N. C.

BOWLER, WILLIAM E., District Line Material Manager, Western Electric Co., Atlanta, Ga.

CLARDY, WILL J., Electrical Engineer, General Engineering Dept., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.

HUMPHREY, GEORGE S., Electrical Engineer' West Penn Power Co., Pittsburgh, Pa.

KAHLER, CHARLES P., Electrical Engineer, Oregon Short Line Railroad (U. P. System), Salt Lake City, Utah.

KELLOGG, CHARLES W., Stone & Webster, Inc., Boston, Mass.

McGREGOR, ANDREW J., Engineer, Ray D. Lillibridge, Inc., New York, N. Y.

PRICE, GEORGE F., Assistant Electrical Engineer, Department of Education, City of New York, Brooklyn, N. Y.

QUENTIN, GEORGE W., Sales Engineer, Duquesne Light Co., Pittsburgh, Pa.

WILSON, GEORGE B., Chief Engineer, Service Section, Apparatus Sales Dept., Canadian General Electric Co., Toronto, Ont.

APPLICATIONS FOR ELECTION

Applications have been received by the Secretary from the following candidates for election to membership in the Institute. Unless otherwise indicated, the applicant has applied for admission as an Associate. If the applicant has applied for direct admission to a higher grade than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the Secretary before February 28, 1923.

Abbink, John, New York, N. Y.
Acly, Harry M., Pittsfield, Mass.
Adams, Merle J., Cleveland, Ohio
Alcus, Lewis S., St. Louis, Mo.
Allan, John, Plainfield, N. J.
Anderson, Arvid E., Schenectady, N. Y.
Anderson, Edward S., International Falls, Minn.
Anderson, John L., Tuskegee Inst., Ala.
Anderton, Robert H., Washington, D. C.
Annappa, M. L., Schenectady, N. Y.
Anthony, William T., Cleveland, Ohio
Bagwell, Omar C., Cleveland, Ohio
Baltzly, Clifford C., (Member), Philadelphia, Pa.
Barry, William G., Cleveland, Ohio
Beck, Herbert H., Fon du Lac, Wis.
Bennett, Arthur F., New York, N. Y.
Berg, Harry A., Ithaca, N. Y.
Berg, Lawrence R., Seattle, Wash.
Berg, Martin H., Milwaukee, Wis.
Bergey, Stanley LaR., Brooklyn, N. Y.
Berkeley, Bryon H., Brooklyn, N. Y.
Biehl, George, New York, N. Y.
Bigalow, Ralph K., Cleveland, Ohio
Bilheimer, A. G. A., Nazareth, Pa.
Billington, Harry C., Lawrence, Mass.
Black, Harold S., New York, N. Y.
Bollier, George J., San Francisco, Calif.
Bonorden, Allen R., San Francisco, Calif.
Booth, William T., (Member), New York, N. Y.
Boulassier, Rene P., New York, N. Y.
Bowen, Herbert R., Cleveland, Ohio
Bowman, Brice, Cleveland, Ohio
Bratt, Donald, E. Pittsburgh, Pa.
Brewster, Louis C., Akron, Ohio
Brogan, Arthur R., New York, N. Y.
Brown, Ernest F., (Member), Atlanta, Ga.
Brown, Henry A., Cleveland, Ohio
Brown, Leon M., Spokane, Wash.
Brownrigg, Abel L., New York, N. Y.
Bumbaugh, Harold L., Stanford University, Calif.
Butler, Samuel F., New York, N. Y.
Caine, Robert C., Cincinnati, Ohio
Cake, Harold H., Portland, Ore.
Callahan, James J., Cleveland, Ohio
Callaway, Allen J., Salt Lake City, Utah
Campion, L. J., Cleveland, Ohio
Carney, James C., New York, N. Y.
Casserly, James F., Cleveland, Ohio
Clark, Jay Rowley, Rochester, N. Y.
Clarke, Fred, Cleveland, Ohio
Cooley, John R., Plainfield, N. J.
Cousins, Robert E., (Member), New York, N. Y.
Craven, William M., Birmingham, Ala.
Csohar, Stephen F., New Brunswick, N. J
Cullun, Uriel X., Chattanooga, Tenn.
Daniel, Homer N., St. Louis, Mo.
Daniels, Harold C., Fairmont, W. Va.
Davies, Leo A., Cleveland, Ohio
Day, Harold P. S., Milwaukee, Wis.
de Arellano, Juan R., Necaxa, Mexico
Deal, Ralph C., Clifton Forge, Va.
Demuth, Orin A., Seattle, Wash.
Denbin, Adolph G., New York, N. Y.
Dennis, Robert E., Mt. Vernon, N. Y.
De Weese, Fred C., Pine City, Minn.
Dibner, Bernard, Schenectady, N. Y.
Drake, Ralph E., New York, N. Y.
Dunbar, Robert V., (Member), New York, N. Y.
Eisen, J., Yonkers, N. Y.
Elder, Maurice E., Ada, Ohio
Eller, Frederick W., New York, N. Y.
Ewing, Francis R., New York, N. Y.
Fairbanks, Herbert N., Quantico, Va.
Fischer, Rudolph E., (Member), Chicago, Ill.
Fiske, C. Stewart, Wilkinsburg, Pa.
Flocus, George N., Pittsburgh, Pa.
Forrest, Henry C., Schenectady, N. Y.
Frothingham, Samuel, Jr., New York, N. Y.
Gale, Gustave W., Cleveland, Ohio
George, Darcy M., Allentown, Pa.
Graeter, George E., Cleveland, Ohio
Graham, David T., Philadelphia, Pa.
Gray, Emmons T., Lancaster, N. Y.
Griffin, Spencer A., Springfield, Mass.
Grimmons, John A., Malden, Mass.
Griswold, Demetrius W., Santa Clara, Calif.
Guett, Monroe, (Member), Hartford, Conn.
Hagemann, Edwin C., New York, N. Y.
Hamilton, Elvin A., Cleveland, Ohio
Hanna, Harry S., Cleveland, Ohio
Hatcher, Charles T., New York, N. Y.
Hayward, Laurence W., Boston, Mass.
Heilman, Russell H., Pittsburgh, Pa.
Heimlich, Herman R., Ft. Wayne, Ind.
Heubel, Frank N., Chicago, Ill.
Hicks, M. H., Chicago, Ill.
Higgins, Ralph, Barberton, Ohio
Hintzelmann, Carl L., Cleveland, Ohio
Hillman, August C., Rutherford, N. J.
Holt, Horace S., Springfield, Mass.
Holz, William E., Cleveland, Ohio
Horn, Karl W., Cleveland, Ohio
Huff, Clayton W., Toledo, Ohio
Hunting, Harold S., Waukegan, Ill.
Huntley, Harold R., Milwaukee, Wis.
Jenkins, Charles H., Los Angeles, Calif.
Johnson, Andrew J., New York, N. Y.
Johnson, Frank C., Bremerton, Wash.
Jones, Frederick M., Schenectady, N. Y.
Jones, Oscar I., Scranton, Pa.
Kaehnie, William L., Cleveland, Ohio
Karcher, John C., Washington, D. C.
Karpf, Leon J., New York, N. Y.
Kassoy, Nathan M., New York, N. Y.
Kenny, Thomas A., New York, N. Y.
King, George E., E. Pittsburgh, Pa.
Kinzly, Nelson T., Nashville, Tenn.
Knapp, Lester H., Keokuk, Iowa
Kratzer, Roy E., Wilkinsburg, Pa.
Layton, L. W., Cleveland, Ohio
Lea, Roland A., St. Louis, Mo.
Lee, Stewart, Jr., Altoona, Pa.
Leh, Howard N., Nazareth, Pa.
Leinard, Howard O., Cleveland, Ohio
Lentz, George W., Pittsfield, Mass.
Lewandowski, Otto H., (Member), New York, N. Y.
Lewis, Frank H., Spokane, Wash.
Lewis, Harry H., Seattle, Wash.
Lindaman, Harvey W., Cleveland, Ohio
Loranger, John G., Cleveland, Ohio
Lough, Alexander I., Cleveland, Ohio
Lynd, Joseph M., Springfield, Ill.
MacAdam, Anthony H., Mt. Vernon, N. Y.
MacLeod, Fred W., Detroit, Mich.
Macy, Ralph G., (Member), Newark, N. J.
Manwaring, Robert A., New Haven, Conn.
Mark, Isaac, Jr., New York, N. Y.
Marshall, William R., Buffalo, N. Y.
Martin, Edmund B., New Orleans, La.
Marter, E. Budd, 3rd, Philadelphia, Pa.
Masters, William A., Cleveland, Ohio
Matern, William H., Schenectady, N. Y.
Meckler, Louis M., Jr., Elizabeth, N. J.
McEntee, Lawrence C., Reliance, Wyoming
McIlvaine, Hubert A., Cleveland, Ohio
McLaughlin, William J., Chicago, Ill.
McQuown, Edward D., Cleveland, Ohio
Michon, Alfred E., New York, N. Y.
Miller, Browning B., St. Louis, Mo.
Miller, Charles E., Stanford University, Calif.
Miller, Daniel D., (Member), New York, N. Y.
Mills, Charles E., Brooklyn, N. Y.
Mills, E. A., Omaha, Neb.
Moench, Charles, St. Louis, Mo.
Moorhouse, J. Bernard, Okmulgee, Okla.
Morris, David H., Cleveland, Ohio
Morrison, Glenn K., San Francisco, Calif.
Moule, S. C., Cleveland, Ohio
Nagy, Frank C., Newark, N. J.
Naiman, Julius M., Chicago, Ill.
Naylor, Clarence G., Atlantic City, N. J.
Nebe, William G., St. Louis, Mo.
Needham, John T., (Member), N. Plainfield, N. J.
Nelson, Stanley F., Atlanta, Ga.
Newmyer, A. D., Ashville, Ohio
Noone, Martin J., Wilkes-Barre, Pa.
Oboler, Max A., Chicago, Ill.
O'Brian, William C., Jackson, Mich.
Okawa, Chukichi, Schenectady, N. Y.
Oliver, W. Frank, Atlanta, Ga.
Owen, George L., Vandling, Pa.
Pancoast, Donald F., Lakewood, Ohio
Parnell, Eric, Boston, Mass.
Pease, Robert M., Washington, D. C.
Pelham, Wilbur, Milwaukee, Wis.
Pengelly, Harry E., Minneapolis, Minn.
Penuel, Wayne B., Atlanta, Ga.
Peterson, Harold O., Belmar, N. J.
Pew, Fred V., Niagara Falls, Ont.
Pitzer, Thomas C., Pittsburgh, Pa.
Platt, Charles J., Jr., New York, N. Y.
Ponsonby, Amos A., Miners Mills, Pa.
Pushee, Jesse M., Housatonic, Mass.
Range, E. C., Newaygo, Mich.
Reed, Carl W., Minneapolis, Minn.
Rhodes, Roy W., Boston, Mass.
Rich, Arnold, New York, N. Y.
Richards, Lee M., St. Louis, Mo.
Riddle, Frank H., Detroit, Mich.
Roberts, Cecil R., Winnipeg, Man.
Rodriguez, Rodolfo C., Mexico City, Mex.
Ronk, Howard D., Kingston, N. Y.
Rosin, Walter E., Milwaukee, Wis.
Ross, Joseph P., Evanston, Ill.
Russell, John Jr., Newark, N. J.
Ryan, John J., (Member), New York, N. Y.
Satterlee, William W., E. Pittsburgh, Pa.
Saunders, Cecil C., Camden, N. J.
Sayles, Edgar V., Jackson, Mich.
Schilling, P. Richmond, Troy, N. Y.
Schleter, George H., E. Pittsburgh, Pa.
Schneider, William G., Anderson, Ind.
Schroeder, Henry J., New Haven, Conn.
Schulenburg, Edward J., Cedar Rapids, Iowa
Schultis, John J., Cleveland, Ohio
Schultz, John D., Atlanta, Ga.
Scribner, Harold W., Stanford University, Calif.
Shakeshaft, Harold I., Binghampton, N. Y.
Sheakley, Clarence F., Pittsburgh, Pa.
Shipek, Adolph, Seattle, Wash.
Siegner, Ralph, Port Orchard, Wash.
Simons, John J., New York, N. Y.
Sismey, Eric D., Penticton, B. C.
Smith, Charles E., Brooklyn, N. Y.
Smith, Chester F., Cleveland, Ohio
Smith, Edward A., Chicago, Ill.
Smith, Granville B., New York, N. Y.
Smith, Harry L., Bridgeport, Conn.
Snyder, Cecil D., Long Branch, N. J.
Sorensen, Bert N., Glacier, Wash.
Spalding, Edward H., Cleveland, Ohio
Spray, Lester E., Swissvale, Pa.
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Stang, Levi C., (Member), Marion, Ohio
Stauffer, L. Maynard, Stanford University, Calif.
Stebbins, Alden H., Toledo, Ohio
Steuerwald, Jacob J., New Orleans, La.
Stevenson, William N., Boston, Mass.
Strott, J. Charles, Baltimore, Md.
Surrell, Allen W., Cleveland, Ohio
Swank, Arthur J., San Francisco, Calif.
Swartwood, Gale K., Nora Springs, Iowa

Taylor, George L., Tacoma, Wash.
Templeman, John D., Cleveland, Ohio
Thresher, Harlow L., Cleveland, Ohio
Tripodi, Don W., Du Quoin, Ill.
Trotta, James P., Tampa, Fla.
Truax, Harlow E., Bremerton, Wash.
Turnbull, Aubrey A., Fairville, New Brunswick, N. S.
Turner, William H., Schenectady, N. Y.
Van Allen, Louie J., Cleveland, Ohio
van der Vegt, John, Schenectady, N. Y.
Votypka, Yaro H., Cleveland, Ohio
Walker, Charles R., Stamford, Conn.
Walthall, Henry B., Atlanta, Ga.
Walthour, F. D., Cleveland, Ohio
Ward, Frank A., Cleveland, Ohio
Watson, Charles W., Rochester, N. Y.
Weaver, Allan, New York, N. Y.
Weems, Chester N., Atlanta, Ga.
Wheatcroft, Edward L. E., Schenectady, N. Y.
Whitaker, Walter C., Jr., Los Angeles, Calif.
White, William C., Chicago, Ill.
Whittaker, Alan D., Ft. Winfield Scott, Calif.
Will, Irving M., Boston, Mass.
Williamson, Harry T., Cleveland, Ohio
Williford, Edward A., Chicago, Ill.
Wilson, Carroll L., Wilkinsburg, Pa.
Wilson, Gerard, Stanford University, Calif.
Wilson, Richard H., (Member), New York, N. Y.
Wilson, William S., Plymouth, Pa.
Wingo, A. C., Los Angeles, Calif.
Winsch, Edwin G., Cleveland, Ohio
Witt, Truman E., St. Louis, Mo.
Worthley, Charles B., Tacoma, Wash.
Wray, Fred L., Cincinnati, Ohio

Total 235

Foreign

de Souza, Antonio R., Pernambuco, Brazil
Gray, Charles M., Hawera, N. Z.
Hirose, Keiichi, Sgibaura, Tokyo, Japan
Hayman, William G. I., Perth W. Aus.
Holmsen, Reidar, Christiania, Norway
Koga, Isaac, Tokyo, Japan
Kusano, Hideo, Shiba Ku, Tokio, Japan
Lovell, William D., Billingham, Stockton-on-Tees, Eng.
Naitow, Yoso, Kyoto, Japan
Manneback, Charles, Brussels, Belgium
Venkatesweren, G. R., Coimbatore, S. India

Total 9

STUDENTS ENROLLED JANUARY 17, 1923

16205 Whitehead, Jesse C., Pratt Institute
16206 Carver, Walter H., Drexel Institute
16207 Knelling, Vincent A., Pratt Institute
16208 Kimball, Carleton B., Northeastern University
16209 Frank, Nathaniel H., Massachusetts Institute of Technology
16210 Healy, Kent T., Massachusetts Institute of Technology
16211 St. Cyr, Alain L., University of Vermont
16212 Williams, Harry E., Pratt Institute
16213 Wm. A. Nichols, Central Technical School
16214 Johnson, Shirley D., Tri State College
16215 Hoerner, Thomas J., University of Wisconsin
16216 Alpern, H. Dwight, Massachusetts Institute of Technology
16217 Almendinger, Harold A., Armour Institute of Technology
16218 Coultrip, Raymond L., Armour Institute of Technology
16219 Dolesh, Frank J., Armour Institute of Technology
16220 Hart, Thomas H., Armour Institute of Technology
16221 Hibbeler, Alvin, Armour Institute of Technology
16222 Krebs, Manfred B., Armour Institute of Technology
16223 Landreth, Morton L., Armour Institute of Technology
16224 Levin, Marvin R., Armour Institute of Technology
16225 Marco, Frederick J., Armour Institute of Technology
16226 Marschall, Peter J., Armour Institute of Technology
16227 Miller, Douglas F., Armour Institute of Technology
16228 Nissley, Harold R., Armour Institute of Technology
16229 Ranson, Richard R., Armour Institute of Technology
16230 Raphling, Joseph J., Armour Institute of Technology
16231 Richardson, Donald E., Armour Institute of Technology
16232 Rohr, Edgar R., Armour Institute of Technology
16233 Rinvaldt, Reinhold H., Armour Institute of Technology
16234 Shaffer, Chester S., Armour Institute of Technology
16235 Swartz, Leslie L., Armour Institute of Technology
16236 Bell, Norman W., Carnegie Institute of Technology
16237 Williams, Lewis R., Kansas State Agricultural College
16238 Stern, Sander, Brooklyn Polytechnic Institute
16239 Niven, Charles K., Pratt Institute
16240 Jackson, V. Guy, Carnegie Institute of Technology
16241 Pyle, Albert J., Massachusetts Institute of Technology
16242 Woodbury, Charles F., Massachusetts Institute of Technology
16243 Plant, Paul R., Massachusetts Institute of Technology
16244 Loud, Charles E., Massachusetts Institute of Technology
16245 York, Verno O., Michigan Agricultural College
16246 Labor, Hal C., Michigan Agricultural College
16247 Kinney, Ernest A., Michigan Agricultural College
16248 Thimme, Edmund J., Massachusetts Institute of Technology
16249 Johnson, Richard R., University of Idaho
16250 Barclay, William L., Jr., Massachusetts Institute of Technology
16251 Monseth, Ingwald T., University of Minnesota
16252 Nee, Harold E., University of Minnesota
16253 Stimart, Elwood L., University of Minnesota
16254 Greene, Chauncey L., University of Minnesota
16255 Huseby, Gisle E., University of Minnesota
16256 McLeland, Lyle K., University of Minnesota
16257 Murdock, George B., University of Minnesota
16258 Lanpher, Murray N., University of Minnesota
16259 Trcka, Benjamin, University of Minnesota
16260 Johnson, Enan C., University of Minnesota
16261 Warren, Laurence C., University of Minnesota
16262 Mabbott, Leonard E. J., University of Minnesota
16263 Pippo, Paul J., Pratt Institute
16264 Hall, Royal, Lewis Institute
16265 Mader, Clarence, Lewis Institute
16266 Stubbs, Frank M., Carnegie Institute of Technology
16267 Washburn, Dale E., Massachusetts Institute of Technology
16268 Townsend, Harold L., Massachusetts Institute of Technology
16269 Gedge, William J., Pratt Institute
16270 Kriegshausser, John, Drexel Institute
16271 Tomlinson, Ferris R., Pratt Institute
16272 Loerch, John H., Brooklyn Polytechnic Institute
16273 Wright, W. G., Cooper Union
16274 Van Steenbergen, Paul G., Pratt Institute
16275 Moody, Charles F., Pratt Institute
16276 Stansell, Arthur H., Pratt Institute
16277 Robinson, Powell, Massachusetts Institute of Technology
16278 Smith, Kilburn M., Massachusetts Institute of Technology
16279 Sands, John W., Massachusetts Institute of Technology
16280 Willis, Elton W., Massachusetts Institute of Technology
16281 Tebo, Julian D., Johns Hopkins University
16282 McAuley, P. Harold, Queen's University
16283 Walker, Samuel W., University of Toronto
16284 Roth, Willard, Ohio Northern University
16285 Agnew, John M., University of Illinois
16286 Holston, James B., University of Illinois
16287 Strege, Henry W., University of Minnesota
16288 Kater, Jozef J., University of Minnesota
16289 Pelley, Lloyd L., University of Minnesota
16290 Lobeck, Torarin E., University of Minnesota
16291 Weber, Hanard P., University of Minnesota
16292 Trask, Alfred S., University of Minnesota
16293 Lambie, Horace H., University of Minnesota
6294 Wellisch, Walton, University of Minnesota
16295 Forbes, Henry C., University of Minnesota
16296 Gardner, Donald H., Massachusetts Institute of Technology
16297 Coughlin, William J., Massachusetts Institute of Technology
16298 Clifford, Lyndon W., Clarkson College of Technology
16299 Gill, Harold D., Oregon Agricultural College
16300 Saunders, William W., Oregon Agricultural College
16301 Cordray, Richard E., University of Notre Dame
16302 Smith, James I., University of Notre Dame
16303 Compton, Harry O., University of Washington
16304 Sorber, A. Paul, University of Washington
16305 Bakeman, Charles T., University of Washington
16306 Lamson, Joseph V., Jr., University of Washington
16307 Briggs, Clifford M., University of Washington
16308 Baxandall, Frank M., University of Wisconsin
16309 Linsley, Frank H., Worcester Polytechnic Institute
16310 Brown, Oral A., West Virginia University
16311 Kelleman, Marlin W., West Virginia University
16312 Rosier, Robert, West Virginia University
16313 Lee, Reuben, West Virginia University
16314 Winter, Arnold A., West Virginia University
16315 Callahan, Paul R., West Virginia University
16316 Hall, Stine R., West Virginia University
16317 Copley, James S., West Virginia University
16318 Addis, Carroll W., West Virginia University
16319 Sonnemann, William K., University of Texas

16320 Miyasaki, Masao, University of Wisconsin
16321 Alifano, Antonio, Brooklyn Polytechnic Institute
16322 Halloran, Delaven, Brooklyn Polytechnic Institute
16323 Cooper, Ralph F., University of Akron
16324 Johnston, Andrew M., University of Toronto
16325 Slater, J. Bert, University of Kentucky
16326 Fest, Fred Wm., University of Kentucky
16327 White, W. Preston, University of Kentucky
16328 Boyer, William A., Montana State College
16329 Denault, Clinton L., Worcester Polytechnic Institute
16330 Hoelz, Carl E., University of Wisconsin
16331 Hudson, Harold A., University of Kansas
16332 Lacrete, Wilfred J., University of Kansas
16333 Hume, Henry W., New York Electrical School
16334 Campeau, Arthur C., University of Utah
16335 Tracy, Harold H., University of Utah
16336 Johnson, Henry A., University of Utah
16337 Becker, Wilfrid A., University of Toronto
16338 Timmons, James S., University of Wisconsin
16339 Chabourel, Alfred, West Virginia University
16340 Pugh, Griffith C., West Virginia University
16341 Hutchinson, Charles E., West Virginia University
16342 Fetsch, Joseph T., Jr., Johns Hopkins University
16343 Meadows, John J., Cooper Union
16344 Frankel, Isidore, Cooper Union
16345 Rafuse, Irad S., Cooper Union
16346 Joseph, William, Cooper Union
16347 Hansen, Christian P., Cooper Union
16348 Engelken, Richard, Cooper Union
16349 Schichtel, Peter E., Cooper Union
16350 Miller, Frederick H., Cooper Union
16351 Murphy, Joseph W., Cooper Union
16352 Reed, Arthur C., University of Alabama
16353 Reed, Orville A., University of Alabama
16354 Harris, Rother L., University of Alabama
16355 Lang, Charles M., University of Alabama
16356 Merritt, Monroe S., University of Alabama
16357 Olivet, Carl McPherson, University of Alabama
16358 Lakeman, John M., University of Alabama
16359 Carlton, Clarence S., University of Alabama
16360 Henneman, Fred G., University of Nebraska
16361 Ellis, Walter R., Oregon State Agricultural College
16362 Tubbs, Wesley E., Carnegie Institute of Technology
16363 Richmond, Laurence P., University of Wisconsin
16364 Greenlaw, Dana S., Worcester Polytechnic Institute
16365 Wightman, Everett G., Worcester Polytechnic Institute
16366 Nee, Sangta, Massachuestts Institute of Technology
16367 Goldberg, Abraham, Massachusetts Institute of Technology
16368 Shermer, Frank C., Drexel Institute
16369 Buckley, James E., Massachusetts Institute of Technology
16370 Tanck, Henry, Massachusetts Institute of Technology
16371 Robin, R. C., Massachusetts Institute of Technology
16372 Dickert, Homer J., Drexel Institute
16373 Putnam, Russell C., University of Colorado
16374 Ragsdale, Charles C. C., Carnegie Institute of Technology
16375 Kahn, Maxwell L., Drexel Institute
16376 Angleman, Kenneth C., Rutgers College
16377 Weitzman, Samuel, Rutgers College
16378 Emley, R. Holmes, Rutgers College
16379 Burks, John E., Jr., University of Kentucky
16380 Hillen, William G., University of Kentucky
16381 Ridgeway, Sam H., University of Kentucky
16382 Thompson, Francis A. C., University of Kentucky
16383 Williams, John K., University of Kentucky
16384 Duke, Clifford A., University of Kentucky
16385 McNair, John W., University of Virginia
16386 Martin, Thomas S. Jr., University of Va.
16387 Bunting, Theodore R., University of Va.
16388 Sack, Carl J., Massachusetts Institute of Technology
16389 Rice, Edward C., Massachusetts Institute of Technology
16390 Newman, Alexander F., Massachusetts Institute of Technology
16391 Rich, Willson C., Clarkson College of Technology
16392 Saxon, Francis A., Georgia School of Technology
16393 Longley, Frank R., Georgia School of Technology
16394 Lane, Thomas G., Georgia School of Technology
16395 Golikoff, Boris A., California Institute of Technology
16396 Laws, Allen L., California Institute of Technology
16397 Ashley, C. LeRoy, California Institute of Technology
16398 Buenafe, Mamerto M., University of Southern California
16399 Robinson, Clarence J., University of Southern California
16400 Mobarry, K. Clare, University of Southern California
16401 Ives, Burdett, University of Southern California
16402 Angermann, William G., University of Southern California
16403 Seaver, Raymond P., Worcester Polytechnic Institute
16404 Holmgren, Eric O., Cooper Union
16405 Meeks, John R., Cooper Union
16406 Holler, William, Cooper Union
16407 Estes, George D., Worcester Polytechnic Institute
16408 Meurer, Sylvain T., Carnegie Institute of Technology
16409 Nash, Paul R., Massachusetts Institute of Technology
16410 Blessing, George, Drexel Institute
16411 Errickson, John, Jr., Drexel Institute
16412 Thompson, Howard A., Stevens Institute of Technology
16413 Farley, William R., Massachusetts Institute of Technology
16414 Clapp, James K., Massachusetts Institute of Technology
16415 Diehm, Charles, Drexel Institute
16416 Vaclavik, Frank J., University of Wisconsin
16417 Topanelian, Edward, Jr., Worcester Polytechnic Institute
16418 Taylor, Richard V., Massachusetts Institute of Technology
16419 Lawton, Frederic L., University of Toronto
16420 Scherer, Jacob A., Drexel Institute
16421 Alexander, Robert, Virginia Military Institute
16422 Coleman, John H., Virginia Military Institute
16423 Turner, Edmond A., Virginia Military Institute
16424 Belden, Arthur W., Virginia Military Institute
16425 Withers, Robert W., Virginia Military Institute
16426 Loveland, Harold A., Clarkson College of Technology
16427 Noyes, Edward E., Brooklyn Polytechnic Institute
16428 Butzer, John D., Bucknell University
16429 Lindskog, Sidney W., Northeastern University
16430 Hubiak, Peter L., Lafayette College
16431 Puyear, Wesley H., University of Michigan
16432 Roberts, Clinton V., University of Colorado
16433 Peters, Ralph C., University of Colorado
16434 Krecek, Joseph A., University of Colorado
16435 DeKraker, Glenn M., University of Colo.
16436 Avera, Bertie L., Georgie School of Technology
16437 Peck, Donald L., Northeastern University
16438 Cooke, Joseph W., Northeastern University
16439 Dobbs, Harry C., Oregon State Agricultural College
16440 Albert, Benjamin, Massachusetts Institute of Technology
16441 Chetham-Strode, Alfred, New Mexico College of Agri. & Mech. Arts
16442 Williams, O. Sherwood, University of Colorado
16443 Winchester, Herbert D., Stevens Institute of Technology
16444 Aalberg, John O., Armour Institute of Technology
16445 Bennett, Percival A., Armour Institute of Technology
16446 West, Paul B., Armour Institute of Technology
16447 Keller, Norman J., Armour Institute of Technology
16448 Stastny, John F., Armour Institute of Technology
16449 Klein, Ernest A., Armour Institute of Technology
16450 Karlsberg, Albert, Armour Institute of Technology
16451 Brown, Harvey L., University of Missouri
16452 Case, James W., University of Missouri
16453 Lockwood, Luther E., University of Mo.
16454 McCormick, Paul W., University of Mo.
16455 Williams, Stuart R., Westinghouse Technical Night School
16456 Methfessel, Carl W., Iowa State College
16457 Donato, Mariano T., University of Notre Dame
16458 Claridge, Richard E., University of Toronto
16459 Clark, Hillis R., Massachusetts Institute of Technology
16460 McMillan, Wylie, University of Illinois
16461 Wade, Edward A., Northeastern University
16462 Caffee, Horace G., Ohio Northern University
16463 Barrett, Howard G., Lewis Institute
16464 Swallow, Richard B., Worcester Polytechnic Institute
16465 Shaffer, Clarence M., Bucknell University
16466 Davidson, Jacob I., Johns Hopkins University

Total 262

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(The Institute is represented on the following bodies; the names of the representatives may be found in the January issue of the Journal and will be published again in the June issue.)

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A. I. E. E. SECTIONS AND BRANCHES

A list of the 47 Sections and 68 Branches of A. I. E. E., with the names of their officers, may be found in the January issue of the Journal.

DIGEST OF CURRENT INDUSTRIAL NEWS

NEW CATALOGUES AND OTHER PUBLICATIONS

Mailed to interested readers by issuing companies.

Fans.—Bulletin 32, 16 pp. Describes the Century line of a-c. and d-c. fans. Among the new fans offered for the 1923 season are the 9-in. and 12-in. induction type single speed a-c. type, wound for the prevailing standard frequencies. The sizes in the a-c. and d-c. multiple speed line are 9-in., 12-in. and 16-in., and 58-in. a-c. ceiling fans. Century Electric Company, St. Louis.

Telephone Wire Data.—Technical data and specifications on "Copperweld" telephone wire and twisted pair, including comparative tables. Copper Clad Steel Co., Rankin, Pa.

Stokers and Fuel Equipment.—Bulletin, 16 pp. A condensed description of the new Frederick multiple retort stoker, Lopulco pulverized fuel systems, Coxe traveling grate stoker, Types E, K and H stokers, Quinn Fuel Oil Burner, Lopulco Coal Dryer, Green Chain Grate Stoker; Arches and Steam Jet Ash Conveyors. Combustion Engineering Corporation, Broad St., New York.

Air Filters.—Folder. Describes the Midwest filter units for purifying air supplied to generators and for other purposes. These units comprise two elements, a steel frame and a filter cell fitting into the frame, with air-tight joints. The cells may be easily removed for cleaning and recharging. These filters are based on the principle of passing the air through layers of small irregularly placed metal cylinders, the surfaces of which are covered with a thin coating of a viscose fluid. Midwest Steel & Supply Co., Inc., 28 W. 44th St., New York.

Motors.—Bulletin 406, 16 pp. Describes the new L-A motor, type H. D. recently developed by the Louis Allis Company, Milwaukee. Among other improvements in this motor is the winding of the rotor, which consists of an integral sheet of copper, punched and formed by a special mechanical process. This one-piece winding is machine wrapped around the rotor core. The single joint is then silver welded. The new motors are made in standard industrial sizes, voltages and frequencies.

Losses in Steam Power Plants.—Folder, 12 pp. Explains the two biggest losses in the steam power plant—(1) the loss in steam turbine economy due to air leakage into the condensing system and (2) the sensible heat in the flue gases lost up the chimney. Describes the new Uehling Combined Barometer and Vacuum Recorder for determining the absolute back pressure in steam turbine and condensing plants, the barometric leakage, the condenser vacuum, the existence of air leakage into the condenser, etc., and the ability of the condenser to handle the load. Uehling Instrument Company, Paterson, N. J.

Electric Lighting.—Bulletins: L. D. 110A, 32 pp., The Lighting of Textile Mills; L. D. 140, 20 pp., The Lighting of Paper and Pulp Mills; L. D. 141, 32 pp., Automobile, Garage and Display Room Lighting; L. D. 142, 16 pp., The Lighting of Woodworking Plants; L. D. 143, 36 pp., Lighting of the Food Industries; L. D. 144, 32 pp., Street Lighting with Mazda Lamps. Since the last distribution, a number of Lighting Data Bulletins have been revised and brought up to date. These include L. D. 108A, Office Lighting, in which the latest practise is pictured and the most recent developments in suitable equipment are discussed. In L. D. 112A, Light and Safety, minor changes and additions have been made. In L. D. 114A, Mazda Lamps Theory and Characteristics, the curves have been revised and extended in range, making them more generally useful. In L. D. 119A The Manufacture of the Edison Mazda Lamp, a description of the new method of packing with the six lamp carton is incorporated. Edison Lamp Works of General Electric Co., Harrison, N. J.

NOTES OF THE INDUSTRY

The Combustion Engineering Corporation, New York, announces the acquisition of the Quinn Oil Burner and Torch Company. Mr. W. R. Quinn, former President of the latter firm becomes associated with the Combustion Corporation as manager of its fuel oil department.

Arc Welding Patents Affirmed.—A decision of the United States Patent Office affirms priority of invention to Claude J. Holslag, Chief Engineer of the Electric Arc Cutting and Welding Company, Newark, N. J. on apparatus and methods for using alternating-current for arc welding by means of a transformer, patents for which were issued June 3, 1919. Sundry companies had taken exception to the award of the patents by the usual means of interference operations. A decision in favor of the Holslag patents was rendered in May, 1922, and the last decision of the Patent Office, January 12, 1923, affirms the previous award of priority as to all the counts.

The National Carbon Company, Inc., Cleveland, now recommends complete brush equipment for synchronous converters. For the d-c. side they recommend their new electrographitic brush 259, which is a material of medium hardness. This brush has successfully replaced soft graphite brushes which have heretofore been considered essential on many types of d-c. machines. For the a-c. side of the converters they recommend Ringsdorff ET-10 for application at all speeds. The agency for the Ringsdorff brushes was taken over by the National Carbon Company after a very thorough investigation of the metal graphite brush field, the results of the investigation showing that the ET-10 was the most successful of all metal brushes, both foreign and domestic, on rotary rings. A supplement to Catalog 37, giving characteristics and recommendations for 259 and ET-10 will soon be ready for distribution.

The Western Electric Company. Organization changes, effective January 15, are announced as follows:

F. A. Ketcham, for the past four years general sales manager, has been appointed general manager of the supply department.

G. E. Cullinan assumes the position of general sales manager. He was formerly central district manager in Chicago.

L. M. Dunn, who for the past three years has been manager of the Eastern District, has been appointed general merchandise manager of the general manager's staff.

W. J. Drury has been made manager of the Eastern District to fill the vacancy created by Mr. Dunn. Mr. Drury has been sales manager of the New York house for the past three years and is succeeded in that capacity by Mr. J. F. Davis, who has been sales manager of the Boston branch for the same period.

T. E. Burger has been made sales manager at Boston. Mr. Burger was for thirteen years connected with the Los Angeles and San Francisco organizations, being sales manager of the former.

W. P. Hoagland has been appointed central district manager in charge of the Chicago and Minneapolis branch houses. For the past three years Mr. Hoagland has been sales manager at Chicago.

J. H. Gleason takes the position of Chicago sales manager. Mr. Gleason has been power apparatus sales manager at Chicago.

H. L. Grant, who for the past four years has been general appliances sales manager at New York, has been appointed Erie District Manager, a new grouping of the distributing houses at Cleveland, Pittsburgh, Detroit and Cincinnati. Mr. Grant's headquarters will be at Cleveland. A. M. Collins continues as manager of the Cleveland house. It is interesting to note that all these changes are in the nature of promotions.